Hydrologic-economic appraisal of inter-basin water transfer projects

by

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Declaration

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Abstract

South Africa's hydrological and geographical characteristics, coupled with the location of a large part of its mineral endowment, required the development of the complex Vaal River Supply System, including inter-basin water transfer (IBT) projects which have been in operation for over twenty-five years. This research compares the actual water transfers of two such IBTs with their original, appraisal stage, predictions. Transfers are shown to be significantly less and also more variable than predicted. Further research reveals that the state of the receiving system has a large bearing on year-to-year decisions regarding transfers. Past appraisals, following what is called the Incremental Approach, do not adequately consider the likely future inter-basin transfer operating regime.

Examination of six case studies, four South African, one Chinese and one Australian, shows that the Incremental Approach is still in general use – despite tools available for an improved approach. A new approach is proposed to upgrade estimations of variable costs associated with water transfers – often substantial life-cycle cost components of IBTs. The generally used unit reference value (URV) measure for appraising and ranking water resource projects in South Africa is also rooted in the economic theory of cost-effectiveness. This shows that the current approach is conceptually flawed; it fails to distinguish between water transfers and effectiveness outputs. The determination of the URV equation is expanded and improved. The upgraded appraisal approach, inclusive of the improved URV methodology, is named the Comprehensive Approach.

A step-wise demonstration of the Comprehensive Approach is provided. Uncertainty regarding future water transfers and associated variable costs are provided for by stochastic simulation modelling. Decision analysis theory is applied to obtain the appropriate input value of variable costs. It is shown that the Comprehensive Approach can lead to an outcome significantly different from the Incremental Approach.

The research provides new insights, placing water resource planning practitioners in a better position to recommend appropriate IBTs in future. These insights can also be transferred to the design of institutional and financial models related to IBTs, as well as the configuration and operation of supply systems including sea-water desalination projects.

Samevatting

Suid-Afrika se hidrologiese en geografiese eienskappe, gekoppel aan die ligging van ‘n groot deel van sy minerale bates, het gelei tot die ontwikkeling van die komplekse Vaalrivier Voorsieningstelsel, insluitend tussen-bekken oordragskemas waarvan sommige al vir meer as vyf-en-twintig jaar in werking is. Hierdie navorsing vergelyk die werklike wateroordragte van twee sulke oordragskemas met die oorspronklike vooruitskattings tydens die beplanning-stadium. Daar word getoon dat oordragte noemenswaardig minder en ook meer onreëlmatig was as wat voorspel is. Verdere ondersoek toon dat die stand van die stelsel, aan die ontvangskant, die besluitneming rakende die jaar-tot-jaar oordrag beïnvloed het. Historiese evaluerings het ‘n “Inkrementele Benadering” (soos hier genoem) gevolg, wat nie voldoende die toekomstige bedryfsomgewing ten opsigte van tussen-bekken oordragte inagneem nie.

Ondersoek van ses gevalstudies, vier Suid-Afrikaans, een Sjinees en een Australies, toon dat die Inkrementele Benadering nog algemeen in gebruik is, ten spyte daarvan dat hulpmiddels vir ‘n verbeterde benadering beskikbaar is. ‘n Nuwe benadering word voorgestel vir die verbetering van vooruitskattings van veranderlike koste wat met wateroordragte geassosieer word – dikwels ‘n aansienlike gedeelte van die lewenssiklus-koste van sodanige skemas. Die Eenheidverwysingswaarde (EVW) maatstaf, wat algemeen in Suid-Afrika gebruik word om waterbronprojekte te beoordeel en in rangorde te plaas, word ook geanker in die ekonomiese teorie van koste-effektiwiteit. Daarmee word getoon dat die huidige gebruik van die EVW konsepsioneel gebrekkig is; dit tref nie ‘n onderskeid tussen wateroordragte en effektiwiteitsuitsette nie. Die bepaling van die EVW vergelyking is verbreed en verbeter. Die opgegradeerde benadering, met insluiting van die verbeterde EVW metodiek, word die Omvattende Benadering genoem.

‘n Stapsgewyse uiteensetting van die Omvattende Benadering word voorsien. Onsekerhede ten opsigte van wateroordragte en geassosieerde veranderlike koste word deur middel van stogastiese modellering aangespreek. Besluitnemingontledingsteorie word ingespan om die toepaslike insetwaarde van die veranderlike koste te bepaal. Daar word getoon dat die Omvattende Benadering tot ‘n resultaat kan lei wat aansienlik verskil van wat met die Inkrementele Benadering verkry word.

Die navorsing verskaf nuwe insigte wat die waterbronbeplanner in ‘n beter posisie sal plaas om gepaste tussen-bekken oordragskemas voor te stel. Hierdie insigte kan ook oorgedra word na die ontwerp van institusionele en finansiële modelle rakende oordragskemas, asook die uitleg en bedryf van voorsieningstelsels, insluitend seewater-ontsoutingsaanlegte.

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Contents

Declaration ii

Abstract iii

Samevatting iv

Acknowledgements v

List of Figures xii

List of Tables xv

List of acronyms, abbreviations and definition of key terms xvii

1 Introduction 1

1.1 Background and problem definition 1

1.1.1 The Incremental Approach of appraisal of IBT projects 1

1.1.2 Problem definition 2

1.2 Rationale 3

1.2.1 Water scarcity and the importance of planning 4

1.2.2 Need for inter-basin transfers 5

1.3 Systems modelling 7

1.4 Study hypotheses and delimitation 8

1.5 Research questions 8

1.6 Purpose of study 9

1.7 Chapter overviews 9

2 Literature review 10

2.1 Introduction 10

2.2 Systems analyses 10

2.2.1 Early development 10

2.2.2 1970 Commission of Enquiry into Water Matters 11

2.2.3 Simulation modelling development in South Africa 12

2.2.4 Systems models developed internationally 13

2.2.5 Conclusion regarding appropriate systems model 14

2.3 Appraisal of water resource projects from an economic efficiency perspective 14

2.4 Decision Analysis in the appraisal of IBTs when dealing with uncertain inputs 17

2.5 Appraisal methods actually applied to IBTs 18

2.6 Summary 20

3 Research method 22

3.1 Introduction and research design principles 22

3.2 Investigation into causes of mismatches between projected and actual water transfers and implications for the Incremental Approach 24

3.3 An assessment of possible changes in appraisal methodology since the availability of probabilistic simulation tools 25

3.4 From the Incremental Approach to an improved Comprehensive Approach 25

3.4.1 Simulating the whole system and determining the probabilistic characteristics of water transfers 25

3.4.2 Estimation of appropriate present value of water transfers and operational costs 27

3.4.3 Rooting the Unit Reference Value (URV) in economic theory 27

3.5 Demonstrating the application and value of the Comprehensive Approach 28

4 Causes of mismatches between projected and actual water transfers 29

4.1 Introduction 29

4.2 Review of historic water transfer data of the Usutu-Vaal GWS (Second Phase) and comparison 29

4.2.1 Description and background 29

4.2.2 Actual transfers since construction of the Usutu-Vaal River GWS 31

4.2.3 Need for investigation 32

4.2.4 Augmentation from the Slang River 33

4.2.5 Combined transfers from Usutu-Vaal River GWS (Heyshope Dam) and the Slang River GWS (Zaaihoek Dam) 35

4.2.6 The VRESAP: Augmentation from Vaal Dam 36

4.2.7 Actual water demand 37

4.2.8 Yield estimations 38

4.2.9 Heyshope Dam record 39

4.2.10 Discussion 40

4.2.11 Conclusions regarding transfers from the Usutu-Vaal River GWS...................... 42

4.3 Examining actual operational decision-making of an integrated water resource system.. 43

4.3.1 Introduction 43

4.3.2 Background 43

4.3.3 Reporting 44

4.3.4 The Vaal River Eastern Sub-system (VRESS) 44

4.3.5 A 22 year view of operational decision-making 47

4.3.6 Discussion and conclusion regarding operational decision-making to explain the difference between projected and actual water transfers 50

4.4 Review of water transfer data of the Tugela-Vaal Government Water Project 51

4.4.1 Background 51

4.4.2 Water transfers from the Thukela River to the Vaal Basin 53

4.4.3 Woodstock Dam level: observed against predicted 54

4.4.4 Thukela-Vaal operational decision-making.. 54

4.4.5 Discussion 55

4.5 Conclusions regarding mismatches between projected and actual water transfers 56

5 Confirmation of Incremental Approach currently in general use 58

5.1 Introduction 58

5.2 Selection of case studies.. 58

5.3 Criteria of assessment.. 59

5.4 Structure of case studies 59

5.5 RSA Case Study 1: Mooi-Mgeni Transfer Scheme – Phase 2 60

5.5.1 Background 60

5.5.2 Summary of investigation.. 61

5.5.3 Discussion and evaluation 64

5.6 RSA Case Study 2: Mkomazi-Mgeni Transfer Scheme... 65

5.6.1 Background 65

5.6.2 Summary of investigation 66
5.6.3 Discussion and evaluation 68
5.7 RSA Case Study 3: Crocodile-Mokolo Transfer Scheme 69
5.7.1 Background 69
5.7.2 Summary of the investigation 71
5.7.3 Discussion and evaluation 77
5.8 RSA Case Study 4: Thukela-Vaal Transfer 78
5.8.1 Background 78
5.8.2 Summary of the investigation 80
5.8.3 Discussion and evaluation 84
5.9 International Case Study 1: The Wanjiazhai Water Transfer Project (First Phase) in the People's Republic of China 85
5.9.1 Background 85
5.9.2 Summary of SAR investigation 87
5.9.3 Post implementation investigation 89
5.9.4 Discussion and evaluation 89
5.10 International Case Study 2: Water augmentation to South East Queensland, Australia 92
5.10.1 Background 92
5.10.2 Summary of investigations 94
5.10.3 Available water resources 95
5.10.4 Postscript regarding SEQ water resource planning 102
5.11 Conclusions regarding the current use of the Incremental Approach in the RSA and internationally 103
6 Towards a Comprehensive Approach 105
6.1 Purpose 105
6.2 Obtaining a probabilistic perspective of likely water transfers 105
6.3 Validation of modelling of water transfers 109
6.4 Stochastic water transfers and variable costs 111
6.4.1 PV of water transfers 111

6.4.2 Water transfer costs ... 112

6.5 Dealing with uncertainty in decision-making: choosing the appropriate PV of electricity costs ... 114

6.6 Reassessing the URV method in view of stochastic water transfers ... 114

6.6.1 Description of the URV measure and its application with the Incremental Approach ... 114

6.6.2 Appropriate denominator of the URV ... 116

6.6.3 URV reviewed ... 117

6.6.4 Application ... 118

6.7 Demonstrating the application of the Comprehensive Approach ... 118

6.7.1 Background ... 118

6.7.2 Water requirement scenarios ... 119

6.7.3 Results from the *Comparative Study* ... 119

6.7.4 The TWP option shadow priced for electricity costs ... 122

6.7.5 Stochastic water transfers costs included in the TWP (shadow priced) ... 123

6.7.6 The stochastic range of the URVs of the TWP ... 125

6.8 Conclusions regarding the development of the Comprehensive Approach ... 125

7 Findings, conclusions and recommendations ... 128

7.1 Background of problem, hypotheses and rationale ... 128

7.2 Mismatches between predicted and actual water transfers ... 129

7.3 Pervasiveness of the Incremental Approach ... 130

7.4 From Incremental to Comprehensive Approach ... 132

7.4.1 Integrated systems analysis ... 132

7.4.2 Variable costs ... 132

7.4.3 Unit reference value (URV) ... 133

7.4.4 Demonstrating the Comprehensive Approach ... 133

7.5 Recommendations ... 133

7.6 Recommendations for further research ... 134

7.7 Conclusion ... 137

References 139

ANNEXURES 150

ANNEXURE 4-A 151

ANNEXURE 4-B 152

ANNEXURE 4-C 155

ANNEXURE 4-D 158

ANNEXURE 5-A 159

ANNEXURE 5-B 160

ANNEXURE 5-C 161

ANNEXURE 5-D 162

ANNEXURE 5-E 163

ANNEXURE 5-F 164

ANNEXURE 5-G 165

ANNEXURE 5-H 166

ANNEXURE 5-I 167

ANNEXURE 5-J 168

ANNEXURE 5-K 172

ANNEXURE 6-A 173

ANNEXURE 6-B 187

ANNEXURE 6-C 192

ANNEXURE 6-D 194

List of Figures

Figure 1-1: The Incremental Approach of appraisal of IBT Projects....................................2
Figure 1-2: Water balance 2000..4
Figure 1-3: Water balance (high scenario) 2025...4
Figure 1-4: Schematic layout of the Vaal River Supply System 6
Figure 2-1: Tagus-Segura IBT: annual water transfers (Note: 1Hm^3= 1 million m^3) 20
Figure 3-1: Research Mapping 23
Figure 3-2: Towards a Comprehensive Approach: Introducing integrated system simulation 26
Figure 3-3: Towards a Comprehensive Approach: Introducing uncertainty of water transfers..26
Figure 3-4: Towards a Comprehensive Approach: Elements affected by reassessment of water transfer characteristics 27
Figure 3-5: Towards a Comprehensive Approach: Inclusion of effectiveness in the URV...28
Figure 4-1: The upper Vaal River system and related IBTs 30
Figure 4-2: Usutu-Vaal River GWS: 1981 projected requirements, transfers and yield increase 31
Figure 4-3: Usutu-Vaal GWS (Second Phase): Historic transfer volumes against transfers predicted in WP F-’81...32
Figure 4-4: 1986 projection of water requirements from the Usutu-Vaal River GWS (Grootdraai Dam)..34
Figure 4-5: Slang River GWS: Historic transfer volumes at Skulpspruit outlet (C1H026)....34
Figure 4-6: Combined historic transfers from the Usutu-Vaal River GWS and the Slang River GWS to the Upper Vaal compared to transfers predicted in WP F-‘81 35
Figure 4-7: Grootdraai Dam storage levels...36
Figure 4-8: Water use from the Usutu-Vaal River GWS (Grootdraai Dam).........................37
Figure 4-9: Heyshope Dam (W5R004) Storage from January 1986 to January 2011 40
Figure 4-10: Percentage water in storage in the Upper Vaal Management Area (Vaal Dam and above) since 1980 41
Figure 4-11: River releases at Grootdraai Dam 42
Figure 4-12: Schematic of the Vaal River Eastern Subsystem (VRESS) 46
Figure 4-13: Locality of the Tugela-Vaal GWP (adapted from Wikimedia, n.d.) 52
Figure 4-14: Historic releases from Sterkfontein Dam 53
Figure 5-1: Schematic of the Umgeni water supply area and the MMTS-2.........................61
Figure 5-2: MMTS-2: Transfers from Spring Grove Dam..62

Figure 5-3: Proposed dams on the Mkomazi River and possible conveyance routes to the Mgeni basin (Adapted from BKS, 2012) ... 66
Figure 5-4: Water demand projections for the Mgeni system (adapted from DWAF, 1999a:24) ... 67
Figure 5-5: Schematic layout of the Mokolo and Crocodile (West) Water Augmentation Project (DWA, 2010a:1-2) ... 71
Figure 5-6: Scenario 9 water requirements (DWA, 2010a:3-3) ... 72
Figure 5-7: MCWAP: Comparison between Scenario 8 and Scenario 9 water requirements ... 73
Figure 5-8: MCWAP water balance for scenario of high population and medium demand management ... 75
Figure 5-9: MCWAP Scenario 8: Net water requirements from Phases 1 and 2 ... 76
Figure 5-10: TWP: Proposed Jana and Mielietuin Dams and pipelines to the Drakensberg Project ... 79
Figure 5-11: Vaal River System water balance: Scenario with high population, CTL in the Free State, and no direct waste water re-use (D3L4High) ... 82
Figure 5-12: Thukela Vaal: Projected transfers ... 83
Figure 5-13: Schematic layout of the Wanjiazhai Water Transfer Project ... 87
Figure 5-14: Stream-flow hydrology of the Fen River at Hejin ... 90
Figure 5-15: Vaal River hydrology (naturalised) at Vaal Dam ... 91
Figure 5-16: SEQ: Locality of the existing and envisaged water infrastructure. (Queensland Water Infrastructure, 2007:1-3) ... 93
Figure 5-17: SEQ Projected Water Demands. (Source: Queensland Government, 2006) ... 95
Figure 5-18: SEQ projected yield vs. demand projection – base-case ... 97
Figure 5-19: SEQ: Desalination only – Alternative 1 ... 98
Figure 5-20: SEQ: Smaller dams on the Mary River – Alternative 2 ... 98
Figure 5-21: SEQ: Augmentation from Clarence River in New South Wales – Alternative 3 ... 99
Figure 5-22: SEQ: Development of smaller dams – Alternative 4 ... 99
Figure 6-1: Map of LHWP with Polihali Dam (Phase II) and the TWP as alternative ... 106
Figure 6-2: Graphical depiction of first five of 995 transfer sequences generated for the Second Phase of the LHWP ... 110
Figure 6-3: Probability density function of PVs of water transfers (8% discount rate and 2010 base year) ... 112
Figure 6-4: Probability of PV of variable costs for total set of 995 sequences (8% discount rate) ... 113

Figure 6-5: Meeting growth in demand by expanding the capacity of the system 115
Figure 7-1: Projected future costs of water supply..137
Figure 7-2: Complete schematic of the elements of the Comprehensive Approach..........138
Figure A-1: Wivenhoe-Somerset System no-failure yield distribution 168

List of Tables

Table 4-1: Yield estimates of the Grootdraai and Heyshope Dams (all units in million m^3/a) 38
Table 4-2: Sequence of firm yield estimates for the Grootdraai Dam system 39
Table 4-3: Woodstock Dam (V1R003): Actual against predicted dam levels 54
Table 5-1: RSA case studies 58
Table 5-2: International case studies 59
Table 5-3: Comparison of options (2008 base year) 63
Table 5-4: MCWAP 2: Discounted Present Values for Option 5 77
Table 5-5: MCWAP2: URV for Option 5 77
Table 5-6: Net Yields of TWP dam options 81
Table 5-7: Thukela-Vaal: Capital cost for Scenario D3L4High 83
Table 5-8: Thukela-Vaal: Derived URVs 84
Table 5-9: Projected water demands and shortages in Taiyuan 88
Table 5-10: Projected SEQ water supply shortfalls 96
Table 5-11: Present value comparison of alternative portfolios to Traveston Crossing Dam (TCD) (2007 Aus$) 101
Table 6-1: First five of 995 stochastic sequences of 41 year transfers generated for the Second Phase of the LHWP 107
Table 6-2: PVs of electricity costs for first five of 995 sequences (8% discount rate, 2010 base year)) 112
Table 6-3: Statistical parameters of electricity costs of set of 995 sequences of water transfers (8% discount rate) 113
Table 6-4: Capital cost of LHWP Ph II (October 2007 Rands) 120
Table 6-5: Capital cost of Thukela Water Project (October 2007 Rands) 120
Table 6-6: High demand: TWP with Jana Dam FSL 890 costing and estimated water transfer 121
Table 6-7: High demand: LHWP (including royalties) costing and estimated water transfer 121
Table 6-8: High demand: URV results (Rand/m^3) 121
Table 6-9: Base demand: URV results (Rand/m^3) 121
Table 6-10: URVs for TWP with high demand and electricity shadow priced: Incremental Approach 122
Table 6-11: TWP: Expected PV of 41 years of water transfers, starting in 2010 and ending in 2050 123

Table 6-12: TWP: Expected PVs of water transfers with base date Oct 2007 123
Table 6-13: PV of water transfers of *Comparative Study* against PV of highest stochastic sequence 124
Table 6-14: URVs for TWP, high demand, with stochastic water transfers and electricity shadow –priced: Comprehensive Approach..124
Table 6-15: Range of results of URVs for TWP High Demand Comprehensive Approach at 8% discount rate 125
Table 6-16: Summary of comparison of Incremental Approach with Comprehensive Approach applied to the TWP (for 8% discount rate).....................................126

List of acronyms, abbreviations and definition of key terms

AOA	Annual operating analysis
ARI	Average recurrence interval
Base yield	The minimum yield over a specified number of consecutive time intervals that can be abstracted from a river or reservoir system fed by a given inflow sequence while attempting to satisfy a given target draft associated with a specified demand pattern for water and a specified operating policy (World Meteorological Association, 2009:II.4-12)
BOT	Build, operate and transfer
CBA	Cost benefit analysis
CEA	Cost effective analysis
CEAS	Central Economic Advisory Services
CPI	Consumer price index
CTL	Coal-to-liquid
CV	Coefficient of variation
DEA	Department of Environment Affairs
DUC	Discounted unit cost
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EIRR	Economic internal rate of return
Eskom	Electricity Supply Commission (South Africa)
EWR	Ecological water requirement
FGD	Flue gas desulpherisation
Firm yield	The maximum base yield that can be attained (World Meteorological Association, 2009:II.4-13)

FSL	Full supply level
GWP	Government Water Project
GWS	Government Water Scheme
HFY	Historic firm yield
HIS	Hydrological information system
HNFY	Historic no failure yield
IA	Incremental Approach
IBT	Inter-basin transfer
ICR	Implementation Completion and Results
IRR	Internal rate of return
IVRS	Integrated Vaal River System
IWRSM	Integrated Water Resources Systems Model
KZN	KwaZulu-Natal
LHWC	Lesotho Highlands Water Commission
LHWP	Lesotho Highlands Water Project
LOS	Level-of-service
m^3/d	cubic meters per day
M&E	Mechanical and electrical
MAP	Mean annual precipitation
MAR	Mean annual runoff
MCDA	Multiple criteria decision analysis
MCWAP	Mokolo and Crocodile (West) Water Augmentation Project
MTEF	Medium Term Expenditure Framework
MWh	Megawatt hours

NPB	Net present benefit
NSW	New South Wales
NWRS	National Water Resource Strategy
OVTS	Orange Vaal Transfer Scheme
PV	Present value
RSA	Republic of South Africa
SANCOLD	South African National Commission on Large Dams
SAR	Staff appraisal report
SEQ	South East Queensland
TCD	Traveston Crossing Dam
TCTA	Trans Caledon Tunnel Agency
TVTS	Tugela-Vaal Transfer Scheme
TWP	Thukela Water Project
URV	Unit reference value
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
VAPS	Vaal Augmentation Planning Study
VRESAP	Vaal River Eastern Subsystem Augmentation Project
VRESS	Vaal River Eastern Sub-System
VRS	Vaal River System
WC&DM	Water conservation and demand management
WEPS	Wholesale Electricity Pricing System (Eskom)
WMO	World Meteorological Association
WP	White Paper

WRC	Water Research Commission
WRPM	Water Resources Planning Model
WRYM	Water Resources Yield Model
WWTP	Wanjiazhai Water Transfer Project

1 Introduction

This chapter provides the background, defines the problem and its relevance, and describes the study hypotheses, delimitation, research questions, and concludes with a brief overview of the dissertation.

1.1 Background and problem definition

Current water resources management in South Africa, a country which can be described as water scarce (Van Niekerk, Van Rooyen, Stoffberg & Basson, 1996:1), is characterised by complexity; intricate systems link water resources with demand centres across catchment boundaries, supplying the metropolitan and industrial regions of the country. The increasing cost of expanding these systems requires that other measures such as water demand management and re-use of water are coming to the fore. The 21st century water resource planner must be able to compare and appraise a wide range of possible solutions, with different and multi-disciplinary characteristics, and provide recommendations that can ensure that water is available for the future – to support the social and economic growth of the country, sustainably and cost effectively. The criteria the planner should use in the appraisal of a possible intervention are also multiple in nature, e.g. economic efficiency (from a national perspective), regional and sectoral distributive characteristics, job-creation potential and environmental impacts.

This study considers one facet of appraisal: the methodology applied to assess the economic efficiency of supply interventions, more specifically inter-basin transfer (IBT) projects.

1.1.1 The Incremental Approach of appraisal of IBT projects

The approach generally applied historically to appraise planned IBT projects, from an economic-efficiency perspective and called here the Incremental Approach (IA), is illustrated in Figure 1-1.

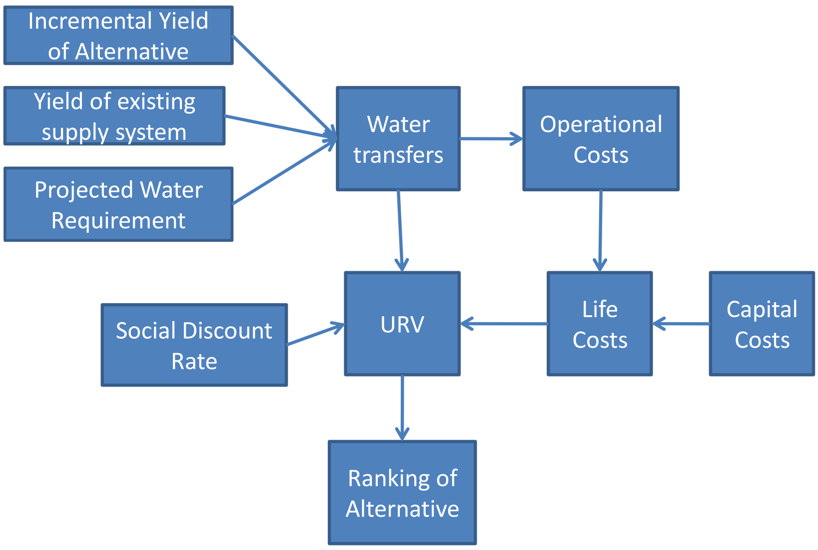

Figure 1-1: The Incremental Approach of appraisal of IBT Projects

The Incremental Approach comprises the following elements:

a) The projection of growth in water demand for the system supply area
b) The determination of the yield of the existing system prior to the inclusion of the IBT project
c) The determination of incremental yield provided by the IBT, the establishment of the point in the future when the IBT project should start to deliver water and the point when the incremental yield from the project is fully utilised. From these the projected annual water transfers from the IBT project are determined
d) An economic analysis that:
    i. assesses the present value of the life time costing stream comprising capital and recurrent (including operational) costs, suitably shadow-priced where applicable and using an appropriate social discount rate
    ii. similarly assesses the present value of the future annual water transfers – the latter assumed to be equal to the incremental demand above the yield capability of the existing system
    iii. determines the unit reference value (URV) of the project by dividing the present value of life time costs by the present value of water transfers
e) The ranking of the project against competing alternatives according to its URV.

1.1.2 Problem definition

In the case of an IBT project with significant variable costs the assumption of the Incremental Approach is that the annual quantity of water to be delivered would exhibit a smooth pattern of growth, at first, and thereafter remain constant into the future. This assumption can be questioned. It can reasonably be expected that there would be times in the future when conditions in the receiving basin do not require water to be imported (e.g. when all the dams are spilling).

As a number of inter-basin transfer schemes have been in operation in South Africa for some time, an ex post facto evaluation to compare predicted transfers with actual transfers made, was undertaken. Two schemes were investigated, the Usutu-Vaal GWS (Second Phase) and the Tugela-Vaal Government Water Project (GWP), reported on in Chapter 4.

The examination of water transfers of the Usutu-Vaal GWS and the Tugela-Vaal GWP, showed in both cases that the actual transfer quantities differed dramatically from what had been predicted; the transferred quantities were considerably less than envisaged at the time these projects were planned and the patterns of the transfers were erratic – not at all smooth as initially foreseen. In both these cases transfers are associated with significant variable costs as water had to be pumped against high static heads for delivery into their respective receiving basins. As can be expected, decision-making in the real world takes into account the hydrological conditions in the receiving basin and the risk of future water shortages by not making transfers, as opposed to incurring the pumping costs, which sometimes will lead to reduced, or no, transfers. The dependency on hydrological conditions therefore causes the transfers to be variable. This, it is proposed, was the main reason for the differences found between what had been envisaged at the planning stage, and what had been experienced in reality.

Pumping is often required in IBT projects. The pumping cost estimations during an appraisal stage could significantly affect the configuration of a project recommended for implementation. It is therefore important that the estimates of the quantities of water to be transferred be as accurate as possible. The above case studies indicated that the standard methodology to appraise the economic efficiency of water resources capacity expansion projects, for cases where water transfers are associated with significant variable costs, either in their application or their specification, may not adequately allow for the uncertain nature of future variable costs. This, therefore, was the issue that led to further examination in this study.

1.2 Rationale

This section motivates the need for this research by addressing water scarcity in South Africa, the concentration of risk during the investigation phases of the lifecycle of water resource infrastructure and the need for IBTs.

1.2.1 Water scarcity and the importance of planning

The National Water Resources Strategy (NWRS) (Department of Water Affairs and Forestry [DWAF], 2004:88) showed that a number of the 19 water management areas in South Africa, as defined at the time, were in deficit, i.e. had greater water needs than resources available, and that this situation was likely to worsen in the future. This is illustrated in Figure 1-2 and Figure 1-3 (Van Niekerk, 2005).

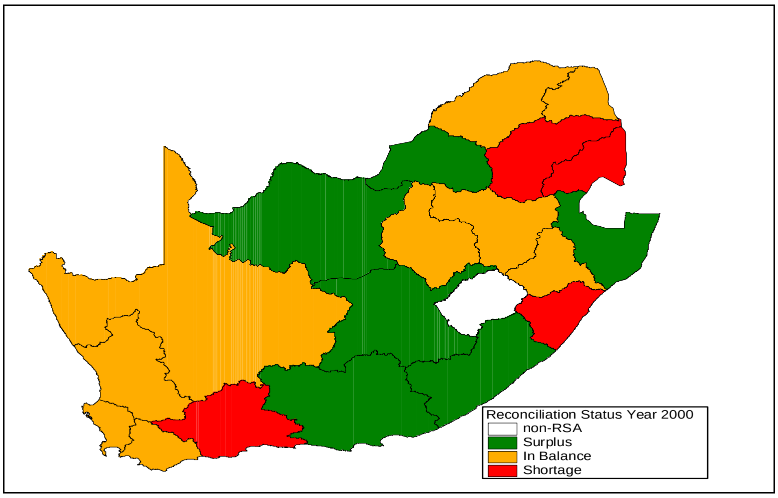

Figure 1-2: Water balance 2000

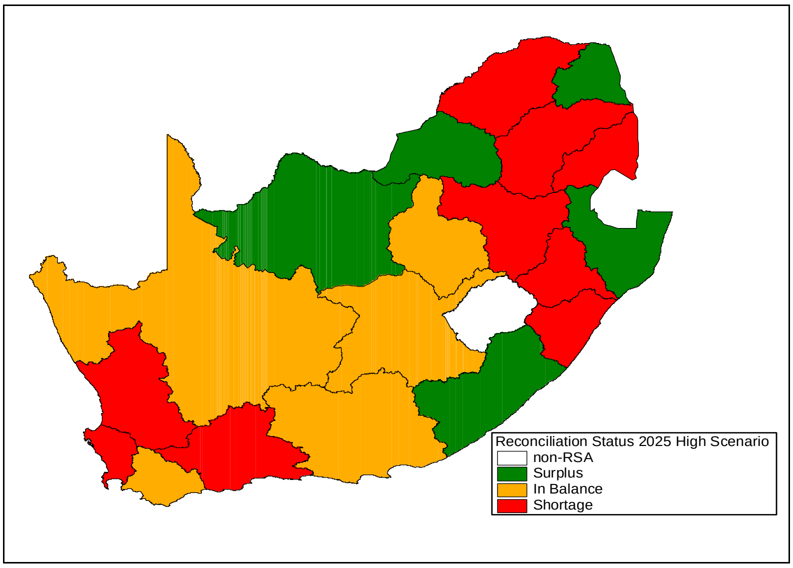

Figure 1-3: Water balance (high scenario) 2025

The NWRS also showed that an appreciable number of the 19 water management areas were reliant on water transferred from other basins (DWAF, 2004:9).

In a recent DWA report that considered scenarios of future water costs to the economy and society, the relative scarcity of water resources in South Africa was again placed under the spotlight (Department of Water Affairs [DWA], 2010f:1-5). *Inter alia* it envisaged the need for an increasing number of future water transfers to meet the water requirements of the major areas of development in the country and forecasted high marginal costs of new water supplies in the medium and longer term (DWA, 2010f:43).

More than forty years ago the Commission into Water Matters (RSA, 1970:9) emphasised the importance of water resources planning for South Africa:

> Planning of our water resources must be thorough, however, not only because of the importance of providing adequate supplies to maintain life and for the advancement of the people, but also because of the enormous capital expenditure required for major water schemes.

The concentration of risk during the investigation phase of a project has also been emphasised by the Department of Finance in its Green Paper on Public Sector Procurement Reform in South Africa (Department of Finance, 1997, par 4.9), and by the World Bank (World Bank, 1999:1).

From the above it can be concluded that the strategic importance of good water resource management in a water scarce country such as South Africa makes it vital that sound water resource planning methodology and the best analytical tools are employed when considering, at the planning stage, the feasibility of interventions to reconcile water demand and supply.

1.2.2 Need for inter-basin transfers

South Africa, for the most part, is a semi-arid country. This, and the fact that its economic heartland lies on the central plateau some 1000 to 1500 meters above sea-level and distant from major rivers, determines that the provisioning of water would, typically, be difficult, costly and complex, and increasingly so as time goes by. Triebel and Van Niekerk (1994:37-39) illustrated the complexity in schematic maps covering the development of the Vaal River Supply System over 60 years; from its modest beginning of a single dam in the Vaal River to a complex multi-reservoir and interlinked system with IBTs spanning seven river catchments and covering a large part of the country, as shown in Figure 1-4.

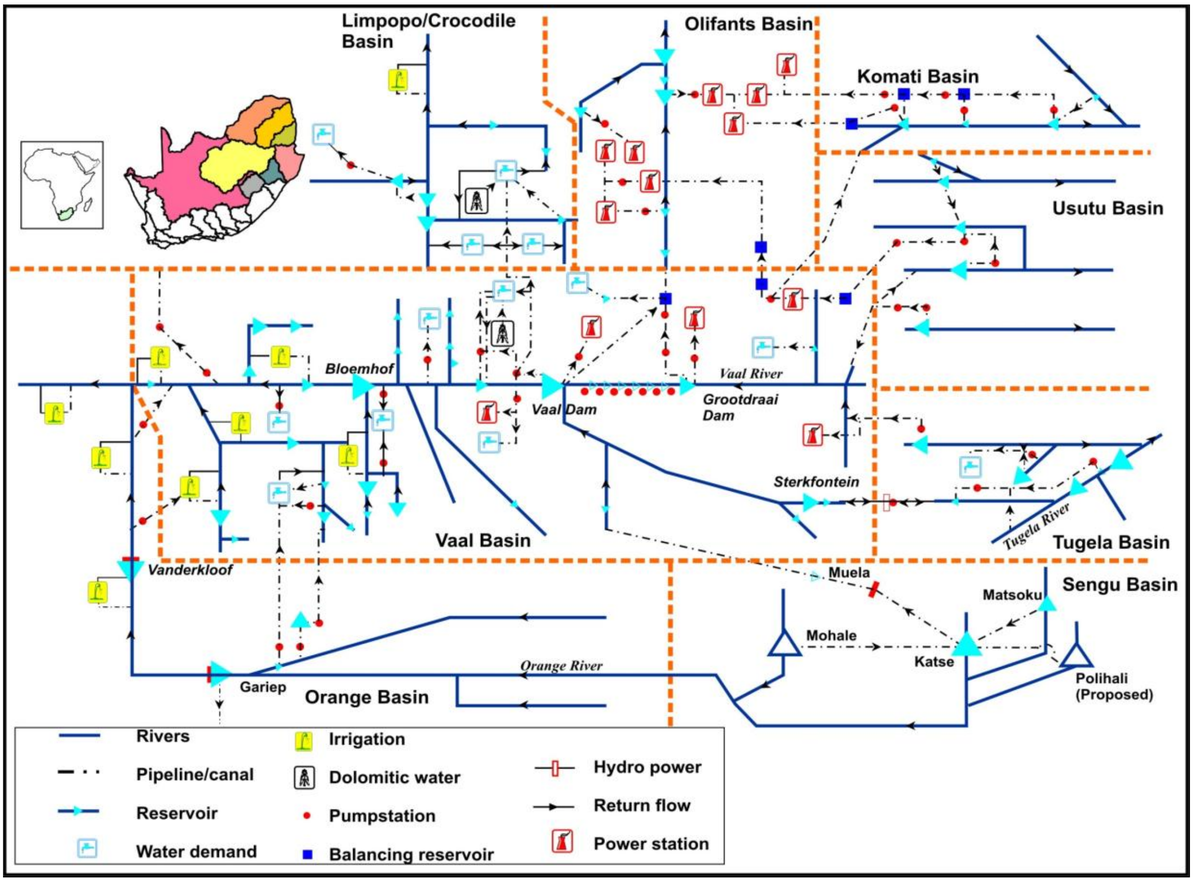

Figure 1-4: Schematic layout of the Vaal River Supply System

The 1970 Commission into Water Matters, in their *Finding 24: Transference of water from regions of surplus to regions of shortage,* remarked on IBTs that, “The solution to our water problems will in future entail the conveyance of more and more water over longer and longer distances” (RSA, 1970:9). Since then enormous investments in such supply systems to serve all the major metropolitan areas of the country have been made. The 2008 estimated total replacement value of all IBTs serving the Vaal River Supply System was estimated at R34 billion (Van der Westhuizen, 2011).

The multiple catchment connected water resource development in the RSA has been a forerunner in Africa, if not the world. Many other countries, especially those with considerable populations in semi-arid areas (e.g. in the north of China and Brazil) have similarly embarked on importation of water by means of IBTs, or are planning to do so – see Caulfield Jr (1986:32), Gichuki & McCornick (2009:358) and Andrade, Barbosa, Souza & Makino (2011:1916). In Africa, the transfer of water from the Zambezi River to the city of Bulawayo in Zimbabwe, the expansion of the existing North-South Carrier that supplies water to Gaborone in Botswana and the importation of water from the Okavango River in

Namibia to link with their Central Water Carrier, are but a few schemes contemplated. (See also extensive listing of IBTs in Snaddon, Davies and Wishart (1999:10-25)).

To meet the growing water requirements of the metropolitan areas in South Africa, where the population is largely concentrated and economic growth occurs, a range of interventions will continue to be required to meet future water demands. From a number of DWA reconciliation studies that took a 20 to 30 year view of likely water requirements and future interventions required, Van Rooyen and Versfeld (2010:11) noted that, while non-conventional measures such as water demand management and water re-use will require far greater emphasis in the future, measures on the supply side, such as IBTs, will still have to be constructed. This was confirmed by McKenzie & Wegelin (2009:171) who investigated the challenges to implement water demand management in the Vaal River System supply area.

South Africa is at a comparative disadvantage vis-à-vis many countries of the world regarding its water resource endowment. With the rapidly increasing marginal cost of future water supplies the careful planning of future interventions to increase water availability, such as IBT schemes, has to be accorded a high importance. It therefore follows that the water resources planning methodology employed must be accurate and lead to optimal recommendations.

In noting the increase in IBT projects, especially in arid and semi-arid parts of the world, to meet water demands, Snaddon et al. (1999:1) stated that “although some IBTs have been technically assessed, such assessments usually are limited to the planning and construction phases, with no follow-through, post-construction”. While these authors focused on the paucity of *ex post facto* ecological studies, the same holds true for *ex post facto* economic evaluation.

1.3 Systems modelling

The technology available at the time the schemes mentioned in paragraph 1.1.2 were planned, was quite different to that which water resource planners have at their disposal today. This is due to the advances in computer technology, and therefore computational and modelling abilities, in subsequent decades. Currently, for example, the water resource planner is able to simulate a complex system with thousands of nodes and linkages, and, applying multi-site stochastic hydrology, explicitly and dynamically determine yields and assurances into the future with growing demands while also allowing for curtailments and capacity expansions.

The DWA developed such a model, initially to deal with the complex Vaal River Supply System but later expanded, improved and modernised. Today this (now called) Integrated

Water Resources Systems Model (IWRSM) is used for decision-making regarding the operation of existing systems as well as in the planning of additions to such systems, in South Africa and, increasingly too, in its neighbouring countries (Basson & van Rooyen, 2001:60).

This study considers whether the use of modern modelling tools is providing an improved prediction of likely future inter-basin transfers and, if so, whether insights that could thus be gained, is being incorporated in the methodology of appraising possible IBT projects to augment supplies to existing systems.

1.4 Study hypotheses and delimitation

The issues identified in paragraph 1.1.2 led to the formulation of a study hypothesis that the Incremental Approach to appraise IBT options to augment existing water resource systems was too simplistic in certain cases and could lead to wrong conclusions.

The sub-hypotheses of the study were as follows:

- *Sub-hypothesis 1:* The Incremental Approach of IBT project appraisal does not adequately consider receiving catchment conditions and a comprehensive systems simulation is required at project appraisal stage if variable costs (e.g. pumping costs) are associated with water transfers.

- *Sub-hypothesis 2*: The Incremental Approach is generally being applied in the appraisal of IBT projects.

- *Sub-hypothesis 3*: The URV method to derive the relative economic viability of an IBT project, and which forms part of the Incremental Approach, requires greater conceptual clarity.

While the study recognises that many factors require consideration when appraising water resource projects, the focus is on economic efficiency and effectiveness. Similarly, in such appraisals, there typically are a number of uncertainties that require analysis and estimation, such as the growth in water requirements and project cost estimates. In this regard the study is confined to uncertainties due to hydrological characteristics inherent of water resource projects.

1.5 Research questions

The study hypothesis and sub-hypotheses were recast into the following four research questions:

Question 1: Why are there differences between the projections of water transfers at the planning stage and the actual transfers after implementation of an IBT and do these differences indicate an inadequacy of the Incremental Approach (IA) of project appraisal?

Question 2: How generally is the IA applied?

Question 3: How can the IA be improved to predict water transfers with greater realism?

Question 4: How must the URV methodology consequently be improved?

1.6 Purpose of study

The purpose of the study was to expand the conceptual understanding and improve the reigning approach of appraising of IBT projects to augment existing water resource systems, thereby making a significant contribution to the existing body of knowledge in this field.

1.7 Chapter overviews

After Chapter 1, which defines the problem and poses the research questions, the literature search follows as Chapter 2, focusing on the theories and methods of water resource systems analysis, economic appraisal, decision analysis and a survey of inter-basin water transfer case appraisal studies actually conducted.

The third chapter describes the research method design to respond to the research questions. This leads to the next three chapters – the body of the research.

Chapter 4 examines in detail an IBT project that had been operational for many years to ascertain the cause of the mismatch between the envisaged and actual inter-basin water transfers. Chapter 5 investigates whether the Incremental Approach is still generally being applied today. Having confirmed that this is still the case, a new appraisal approach, called the Comprehensive Approach, is introduced and its application demonstrated in Chapter 6.

The final chapter, Chapter 7, summarises the findings of the research and suggests further research to follow.

2 Literature review

This chapter describes the literature review undertaken for the study.

2.1 Introduction

A review was conducted to ascertain whether the research questions posed in paragraph 1.5 have been addressed in existing literature. An extensive search of journals in the water resource field provided many references to IBTs. It showed that recent work largely focused on social, environmental, institutional, legal, political and decision-support aspects – e.g. Snaddon, Davies and Wishart (1999:1-97), Yevjevich (2001:345-347) and Andrade, Barbosa, Souza & Makino (2011:1915-1934) – but it bore no fruit regarding the research questions posed for this study. This focus was confirmed in the encompassing book by Ghassemi and White (2007) of case studies on inter-basin water transfers internationally, across three continents. The conclusion is thus drawn that this particular issue has not been addressed and reported on before. Communication with academics at Harvard University (Briscoe, 2011), and the Research Centre for the Management of Agricultural and Environmental Risks in Madrid (Garrido, 2011) and staff at the World Bank (Jagannathan, 2011) could point to some cases where the actual water transfer of an IBT was found to be considerably less than expected. Some of these references were investigated further to see whether there are parallels to the experience in South Africa.

The remainder of the review therefore concentrated on literature that could assist in addressing the research questions. It is divided into three broad themes; literature on the analysis of water resource systems, literature on the appraisal of water resource projects, in general and with stochastically variable cost components, in particular, and literature that could be used to empirically assess the appraisal methodology applied in the cases of IBTs with significant variable costs.

2.2 Systems analyses

As it was considered that systems analysis tools would assist in addressing Research Question 3, *How can the IA be improved to predict water transfers with greater realism?*, a review was conducted of tools that could be employed for that purpose. Some background to system-tool development is provided first; thereafter features that would be important are sourced from the literature for a selection of tools, from which a suitable tool is selected.

2.2.1 Early development

Historically the tools to analyse the operation of complex water resource systems originated in the United States of America (USA). Already in the 1950s the need to plan economically efficient water resource systems came strongly to the fore in the USA in response to the huge public investments made to "green the desert", i.e. develop the Western USA in the first half of the twentieth century. The Harvard Water Programme of the Graduate School of Public Administration conducted research in systems design from 1955 to 1959 which led to the publication of the seminal book, *Design of Water-Resource Systems* (Maas, Hufschmidt, Dorfman et al., 1962). This book was followed a few years later by another well-known work, *Water Resources Systems Engineering* (Hall & Dracup, 1970).

Maas, et al. (1962:250) covered a wide range of tools and techniques with the objective of attaining greater optimality in systems design. Operational analysis type optimising mathematical tools, such as linear programming and dynamic programming, were described in detail and examples, although simplified, demonstrated their application. In recognition of the (then recent) advent of the computer and the new possibilities it offered, the book recommended its use in the application of simulation, especially where systems were diverse and complex.

Hall and Dracup (1970:84) defined simulation as "reproducing the essence of a system without reproducing the system itself", and added, "the essential characteristics of the system are reproduced in a model which is then studied in abbreviated time scale". They found simulation only appropriate for water resource systems of great complexity that were not "mathematically tractable".

While Hall and Dracup (1970:85) noted that "a computer-simulation procedure has been called a technique of last resort", this statement should be viewed against the position at that time when computers were slow and expensive. That situation has changed dramatically – with the computational capacity available today, simulation has become the technique of choice, as is discussed later.

2.2.2 1970 Commission of Enquiry into Water Matters

The rapid expansion of knowledge in the field of water resource systems engineering did not take long to reach South African shores: the 1970 Commission of Enquiry into Water Matters found that "advanced techniques based on systems analyses…to ensure optimal management of multi-purpose multi-unit schemes" are required to deal with the increasing complexity of the water supply systems in South Africa (RSA, 1970:6).

In their recommendation number 19 entitled "Systems analyses for linking water resources", the Commission stated, "when more than one dam is linked to a water supply complex, and, more especially, when dams in several rivers are linked, advanced systems analysis techniques are needed to facilitate optimisation of water resource utilisation" (1970:20) and referred to the studies undertaken in the planning of the Tugela-Vaal IBT project. They recommended that “advanced systems engineering techniques be applied in all such studies” (1970:33).

In an address at a 1994 conference on water engineering in South Africa in tribute to the late Prof Des Midgley, Prof Nathan Buras of the University of Arizona looked back on thirty years of application of systems analysis in water resources engineering and commented that there was an ebb and flow; a great enthusiasm in the 1960s and 1970s was followed by a period of “disappointment and apathy” (Buras, 1994:16). This related, too, to his observation that a gap existed between the research in this field and its application. While this may be true for South Africa, regarding optimisation models, simulation modelling was enthusiastically adopted, as described in the next paragraph.

2.2.3 Simulation modelling development in South Africa

In 1984 a project was started by the DWA to build a systems simulation model for the Vaal River Supply System (see Figure 1-4) which serves the economic heartland of the country. Van Niekerk and Basson (1993:3) reported on the development of the system simulation model: it was based upon the (so-called) Acres Reservoir Simulation program, using an out-of-kilter network solver as basic algorithm. This model was linked to an autoregressive moving average multi-site stochastic stream flow generation package, specifically developed to reliably represent the highly skewed and variable stream flow conditions typical of a semi-arid climate. It was called the Water Resource Yield Model (WRYM) and used to determine the probabilistic yield characteristics of the overall system, as well as its various sub-systems.

Van Niekerk and Basson (1993:3-4) also described how the adding of real-time features to the WRYM led to the development of the Water Resource Planning Model (WRPM). The WRPM could accommodate multiple demand centres (i.e. yield channels), could take into account growth in demand and changes in land use, allow expansion of the system at future dates, deal with quality constraints, and impose curtailments.

The theory that underlay the development of these models is described in a book, *Probabilistic Management of Water Resource and Hydropower Systems* (Basson, Allen, Pegram & Van Rooyen, 1994:20-24) and it provides the nomenclature for the different types of yield, such as base yield, firm yield, secondary yield and average yield. This was an important contribution towards standardising the hydrological concepts in general use today.

Little, Van Niekerk, Pyke and Shand (1994:24) described the application of the WRYM and WRPM to the water supply system in the Western Cape and noted that certain improvements were made which extended the model's general capability as the sub-systems of the Western Cape system did not provide support in a "sequential and unidirectional" way, as was the case in the Vaal System, but supported the metropolitan area directly.

In their *Guide to Hydrological Practices*, the World Meteorological Organisation (WMO) (2009:4-18) stated that "it is evident that determination of the yield characteristics, as well as operational management of multi-reservoir water resource systems, can be very complex and can generally be done solely with the aid of sophisticated computer models". They added that "it is strongly recommended to add a probabilistic dimension to the management of multi-reservoir water resource systems" and mentioned that the models developed by the DWA were ones that would be suitable for such application.

2.2.4 Systems models developed internationally

Wurbs (2005:101-123) selected fifteen reservoir/river system models as "representative of current modelling capabilities and having a record of successful application by water management agencies in support of actual decision making". These included models developed by the US Corps of Engineers (USACE), the US Bureau of Reclamation (USBR), US state agencies and universities as well as models developed by international firms and institutions. Amongst the latter were the Acres Simulation model, which formed the basis of the WRYM and WRPM models described in paragraph 2.2.3 above, as well as the MIKE BASIN model of the Danish Hydraulic Institute which is also frequently used in South Africa. Wurbs described in greater depth five of these models; SUPER and ResSim of the USACE, RiverWare of the USBR, MODSIM of the Colorado State University, and WRAP of the Texas Water Resources Institute (2005:134-152). He compared these according to the following criteria: organising computational structure; modelling environment and user interface feature; modelling capabilities for various types of applications; special modelling features such as reliability and frequency analyses, economic evaluation capabilities; water quality modelling and surface/groundwater interactions; accessibility and documentation, and institutional dimensions of model evolution (2005:153). He concluded that the latter models all meet basic requirements and that the choice of model depended on the specific application, e.g. whether it is required for investigations regarding flood control, water supply, hydroelectric power, navigation, recreation, or environmental management.

Watson, Haasbroek, & Strzepek (n.d.:1-15) described a scoping exercise undertaken in 2008 to ascertain whether it would be advisable for the Department of Water Affairs of South Africa to migrate to internationally available water resources models. Three US based models (WEAP, RiverWare and G2) and three European based models (MikeBasin, Ribasim and Waterware) were compared to the South African developed suite of models described in paragraph 2.2.3 . It was found that all the models, except G2, could be candidates, but further testing of the models on a detailed catchment study was recommended. The one feature that none of the international models could better was the explicit analysis of risk of the South African WRYM and the WRPM models.

2.2.5 Conclusion regarding appropriate systems model

From the literature it is concluded that the systems analysis simulation modelling techniques developed in South Africa, and currently generally applied to the large water resource systems in the country, is at the forefront of practical application of this kind of technology globally and has the essential features to assist in this research. This is particularly true for the risk based modelling features that are expected to play an important role in addressing the research questions of this study. Due to their ubiquitous use, which also makes it easier to obtain past results if required, it is not necessary to look any further than WRYM and WRPM models for this study.

2.3 Appraisal of water resource projects from an economic efficiency perspective

The methodology to appraise water resource projects from an efficiency perspective has not changed significantly since early publications specific to the subject, such as *Water Resources Projects Economics* by Kuiper (1971). Many books written since have broadened the appraisal (sometimes also called evaluation[1]) methodologies with techniques such as multi-criteria decision analysis (MCDA), so as to include in the analysis environmental sustainability and social objectives such as equity and job creation. Kuiper distinguished between what he called cost comparison, cost comparison including risks, and benefit-cost analysis. The first is the most simplified appraisal technique and more often called in the literature the least-cost approach.

Least-cost approach is used to choose between projects with the same or very similar objectives and when these objectives are difficult to quantify in monetary terms (Republic of South Africa, National Treasury, 2010:6). The project with the lowest present value (PV) is favoured. The Centre for International Economics (2009:28) of Australia described the least-cost approach as an analysis that assumes that an extra unit of water offers the same benefits, irrespective of the kind of intervention. Therefore, “the focus of the analysis is on

[1] In some quarters, e.g. the World Bank, this term is reserved for an *ex post facto* review of the success of a project.

the costs of alternative projects given that all projects are assumed to deliver the same benefits".

Cost Benefit Analysis (CBA) (which is the same as what Kuiper called benefit-cost analysis) is primarily used to assess economic efficiency of resource allocation (as opposed to other analytical instruments such as MCDA as mentioned above). The Water Research Commission (WRC) publication, *A manual for cost benefit analysis in South Africa with specific reference to water resource development* (Conningarth Economists, 2007), provides the basis for applying CBA in the water sector in the RSA.

Recognising the difficulty of placing a monetary value on benefits, such as in public programmes, Boardman et al. (2011:464) described the application of cost effectiveness analysis (CEA) and stated that "if the effectiveness measure captures most of the benefits, then it may be reasonable to use CEA to avoid the burden of conducting a CBA". While CEA can be used to assess the technical efficiency of undertaking a certain measure, a CBA is required to assess its allocative efficiency, i.e. "whether something is worth doing" (2011:484).

One of the constituent factors used in the CEA, as well as the CBA, method, and which has elicited much debate in the literature in the past (see, e.g., Boardman et al., 2006:268-269), has been the choice of an appropriate rate for discounting costs and benefits. The debate seems to have converged to a consensus that a real social discount rate of return should be used. In the original CBA Manual (Central Economic Advisory Services, 1989:39) the rate of 8% was proposed for capital investments and, more recently, Conningarth Economists (2007:67-68) found that this rate remained appropriate for South African conditions.

In the CBA the cost and benefit streams are discounted to their present value (using the real social discount rate of return) to determine net present benefit (NPB) and the internal rate of return (IRR) or benefit-cost ratio. When undertaking a CEA the present value of the cost stream is the object of minimising for a specific output, usually a water supply figure.

In undertaking the CBA, scenarios in which certain parameters are changed are often analysed to test for uncertainties in estimates of costs and benefits. More formal mechanisms, e.g. by using Monte Carlo simulations, have also been used to analyse risk when making decisions based on these analyses (World Bank, 1999:5).

Boardman et al. (2006:166) stated that assigning probabilities to occurrences of various contingencies puts one in a position to deal with uncertainties of the future as a problem of assessment of risk. In not too complex situations, these can be incorporated into CBA through expected value analysis. In complex situations the pragmatic approach is to do a partial sensitivity analysis where a single assumption (i.e. one parameter) is changed while the others are kept constant and the results are monitored (2006:175).

CBA is not normally applied when water supply options to metropolitan areas, i.e. for municipal and industrial use, are investigated. On the one hand the benefits are difficult to quantify, on the other hand, when quantified, the results show that the benefits, i.e. marginal value of water in the proposed use far outstrips water cost and often, too, values in alternative uses. When comparing the value of Orange River water for use in Gauteng, for instance, it has been found that the value of production output per unit volume of water in Gauteng was some 240 times that of the irrigation sector in the Orange basin (DWA, 1998:B16).

The Unit Reference Values (URVs) mentioned in paragraph 1.1.1 provide a measure of cost vs. effectiveness and are therefore completely analogous to the CEA in respect of the methodology followed. URVs are generally used by planners of Government Water Works in South Africa to rank options and ascertain best configurations of projects[2]. Similar to the CBA (or CEA), cash flows to construct, operate and maintain a particular scheme are discounted over its economic life, usually 30 to 45 years. It is standard practice to also do a sensitivity analysis round the 8% discount rate, typically using discount rates of 6% and 10%.

Implicit in the URV derivation is the assumption that the benefit that can be derived from such a project can directly be measured, or assessed, as the quantity of water delivered (Mullins, 2011).

Herrington (2006:257-258) mentioned the need in Britain in the 1970s for a “unique measure of the incremental cost of a given scheme so that options could be filtered out” and provided a definition for such a cost-effectiveness measure, called *discounted unit cost* (DUC), as “the PV of supply costs over a suitable horizon divided by the present worth of water actually delivered to meet a deficit over that time”. The DUC used in Britain was therefore completely analogous to the URV in common use in South Africa.

Marginal URVs are used to optimize sizes of projects, e.g. to obtain the best size of a dam. The increase in URV per unit yield by increasing the height of a dam (thereby increasing storage and yield) is compared with the likely URVs of other options that may follow later

[2] Google search (28 May 2011) gave no references to the use of URVs (other than references to DWA reports and related South African articles).

(e.g. a dam at a different location, or a later raising of the same dam). This method was employed in a recent study into the possible raising of the existing Clanwilliam Dam (DWA, 2008:99).

2.4 Decision Analysis in the appraisal of IBTs when dealing with uncertain inputs

The discipline of decision analysis was developed to deal with decisions that involve significant cost, major uncertainty, long time horizons and complex value issues (Howard, 1983a:7). While all the latter factors are relevant in decision-making around IBT projects, it is the uncertainty of future water transfers that may require, as hypothesised, a new appraisal approach and tools. It may be instructive, therefore, to take cognisance of some of the principles and techniques in the field of decision analysis.

Growing from a branch of engineering, *systems analysis* combined complexity and dynamic aspects of a system. *Decision analysis* combines uncertainty and preference with systems analysis. Staël von Holstein (1983:131) described it as “a merger of two fields”:

> Decision theory provides the philosophy of logical behavior in simple decision situations under uncertainty. Systems analysis ... represents systems and modelling methodology, which captures the interactions and dynamics of complex problems. The result is a theory and methodology that allow the analysis of complex, dynamic and uncertain decision situations.

Goodwin and Wright (1998:5) noted that decision analysis provides *rationality*, i.e. based on “a set of rules (or axioms) which most people would regard as sensible” for decision-making. This is analogous to the model of the “*rational economic man*, a key concept in economic theory” where it is assumed that the decision-maker strives to be rational and decisions are based on normative decision models (French, Maule and Papamichhail, 2009:17-18).

French et al. (2009:16) described the *subjective expected utility* model for dealing with uncertainty and risk where a subjective probability distribution is combined with a utility function based on a decision-maker’s preferences, to obtain expected utilities of different actions. Though sometimes difficult, outcomes are usually valued in monetary terms as “logic demands that they be approached directly in monetary terms if monetary resources are to be allocated” (Matheson & Howard, 1983:29).

A decision-maker’s attitude towards risk is one of the important preferences that require encoding in the application of decision analysis. The encoding, which must meet the logic of decision theory (see North, 1983:118-119, Matheson & Howard, 1983:43, and Goodwin & Wright, 1998:115-118 for more detail), will provide the utility derived from an action, based on a the decision-maker’s attitude to risk. A decision-maker can be described as risk-averse, risk-neutral or risk-prone (French et al., 2009:237) depending on the form of the utility function thus derived. Most individuals can be regarded as risk-averse where they would be willing to forego a risk premium to have certainty of an outcome of an action. The certain equivalent (also called certainty equivalent) is the value where the decision-maker is unable to choose (i.e. equivocal) between undertaking an action with a certain outcome of that value against one with an uncertain outcome (and, in the case of a risk averse decision-maker, a higher expected value). In the case of a risk-neutral decision-maker the certain equivalent of an action would be equal to its expected value.

As inter-basin water transfer projects typically are undertaken as public works, the decision-maker will be the government. It is normally assumed that governments, due to their size, are virtually risk indifferent (Howard 1980:16). Accordingly it is not necessary to model risk preferences in these cases; it assumed that the decision-maker is an expected value decision-maker.

The effect of fluctuations of a state variable, i.e. a variable not under the decision-maker's control, is typically tested for a range between the 10th and 90th percentile points of its probability distribution (Matheson and Howard, 1983:29).

2.5 Appraisal methods actually applied to IBTs

A number of studies to appraise potential projects to transfer water across watersheds have been undertaken in South Africa in the last number of years. Some of these involved pumping of water, and therefore had significant costs associated with the quantities of water to be transferred. These are listed as follows:

a) An investigation was undertaken for the Trans Caledon Tunnel Authority (TCTA) by BKS consulting engineers to determine the best option to transfer water from the Spring Grove Dam on the Mooi River, near Rosetta in KZN, to the upper reaches of the Mgeni River above Midmar Dam. A gravity tunnel option was compared to an option to pump water over the divide between the two catchments (Republic of South Africa, Trans Caledon Tunnel Authority, 2009)
b) A report was compiled for Mhlatuze Water by the firm WLPU on the best alternative to augment the water supplies to the Greater Richards Bay/Empangeni area. This involved further pumping of water from the Thukela River (Mhlatuze Water, 1998)
c) A report was prepared for the DWA by Africon in association with Kwezi V3 Engineers, Vela VKE, and WRP Consulting Engineers on a study to provide more water for the growing number of the coal-based industries on the Waterberg coal deposit in the Lephalale area, such as Eskom's Medupi Power Station. The study

investigated transferring water from the Crocodile (West) River to the Mokolo River basin (DWA, 2010a)

d) The Department of Water Affairs and Forestry (DWAF) undertook an extensive study, the Vaal Augmentation Planning Study (VAPS) to look at the possibilities to augment the water resources of the Vaal River System. One of the components of this study comprised analysing a wide range of alternatives to augment the Vaal from the Thukela River basin. The economic analysis prepared by Knight Piesold consulting engineers identified the most attractive options (DWAF, 1994)

e) Subsequent to the VAPS study (see above), the DWAF undertook a feasibility study to identify the best option to transfer water along a (so-called) Southern Route. The economic justification of the project, called the Thukela Water Project, was an important consideration and the report was prepared by the firm BKS (DWAF, 2001a)

f) A study to compare the possible Thukela Water Project with the second phase of the Lesotho Highlands Water Project (LHWP) was undertaken by the DWA. The report was prepared by ACER (Africa), BKS, DMM Development Consultants, Golder Associates Africa and WRP Consulting Engineers (DWA, 2010e)

g) A study was undertaken by the firm Ninham Shand for the DWAF, in conjunction with Umgeni Water, to select a preferred layout and configuration of an IBT to transfer water from the Mkomazi River to the Mgeni River system. The investigation was done in two parts; a reconnaissance part first, followed by the pre-feasibility study, completed in May 1999 (DWAF, 1999a).

In addition to the South African studies, information on the following international cases was obtained:

a) An investigation into the Traveston Crossing Dam to augment the water supplies to South Queensland, Australia, with its centre the City of Brisbane, and the review of the economic aspects of the Traveston Crossing Dam Environmental Impact Assessment documentation by the Centre for International Economics prepared for the Department of Environment, Water, Heritage and the Arts Review of the Australian Government (Centre for International Economics, 2009)

b) An appraisal by the World Bank regarding a proposed IBT in China to transfer water from the Wanjiazhai Dam on the Yellow River to Taiyuan, in the Fen River basin (and later to be extended too to Datong and Pingshuo) (World Bank, 1997)

c) An implementation completion and results report on the first phase of Wanjiazhai Water Transfer Project by the World Bank where it was found that less water was transferred by the project than envisaged during the appraisal in 1997. The reasons are ascribed to greater efficiencies in water use in the receiving basin as well as structural changes towards a less water-intensive economy in the region. (World Bank, 2007:3)

d) Limited information could also be obtained on the Tagus-Segura inter-basin transfer scheme in Spain. The scheme was designed to transfer 1000 million m^3/a from the relatively water rich Tagus River system in the centre to the drier Segura River basin to the south, but transfers since 1980 averaged only 300 million m^3/a (Andreu, Capilla and Sanchis, 1996:285). Water is pumped against a static head of 262 m and conveyed by a 250 km aqueduct of a capacity of 33 m^3/s (1996:286-287). Since 1996 somewhat more was transferred, as can be seen from Figure 2-1 but it is clear that transfers were highly irregular from year to year (Government of Spain, 2012).

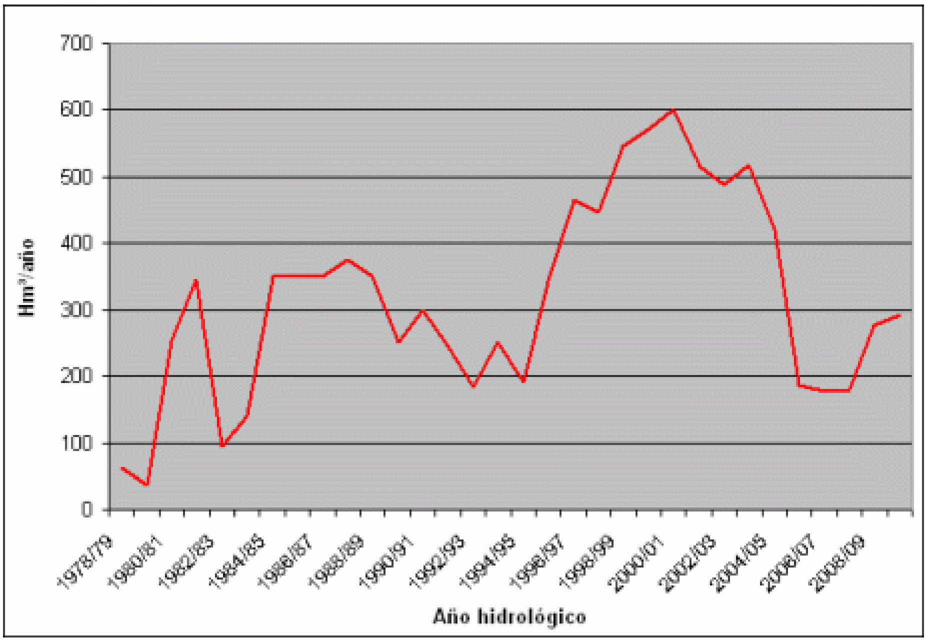

Figure 2-1: Tagus-Segura IBT: annual water transfers (Note: 1Hm^3= 1 million m^3)

It is evident that IBTs are continuously being contemplated, not only in South Africa, but internationally as well. In this study a selection of case studies, sourced from the above two lists, and based on criteria described in paragraph 5.2, were examined in detail.

2.6 Summary

It was mainly due to the location of its mineral endowment coupled with its specific hydrological and geographical characteristics that required South Africa to develop complex water supply systems including large inter-basin transfer projects earlier than most other countries; a number of IBTs have been in operation for more than 20 years. The relative earliness is probably the reason why the issue described in Chapter 1 – that the envisaged water transfers of these IBTs did not agree with the transfers that actually occurred, raising questions about the existing approach to appraisal of IBTs – has evidently not been described in the literature.

The RSA has also been at the forefront of development of simulation models to assist with decision-making in the operation, as well as capacity expansion, of water resource supply systems. It was shown that the models presently used by the DWA are suitable for the simulations to obtain stochastic water transfer data outputs.

Relative aspects of economic theory as well as decision analysis theory were described for use in the construction of a revised approach to the appraisal of IBT projects.

A number of reports and other literature on actual and potential water transfer projects, in the RSA as well as internationally, were sourced. These formed the basis for the selection of case studies reported on in Chapter 5.

3 Research method

This chapter describes the research method used in the study.

3.1 Introduction and research design principles

Case study research is recognised as an acceptable research method, is often used in the social sciences, and many books, e.g. by Stake (1995), Yin (2009 & 2012) and Swanborn (2010), have been written to provide guidance for its application.

Yin defined a case study as, “An empirical enquiry about a contemporary phenomenon, set within its real-world context – especially when the boundaries between the phenomenon and the context are not clearly evident.” Furthermore, case study research “assumes examining the context and the complex conditions related to the case(s) being studied and are integral to understanding the case(s)” (Yin, 2012:4).

While some authors, e.g. Stake (1995:9), see case study research as part of qualitative research, Yin (2009:19) recognises that case study research can “go beyond qualitative research, by using a mix of quantitative and qualitative evidence”. The case studies covered in this research fall within the latter category.

Yin (2009:35) emphasises the importance of theoretical propositions to guide data gathering and analysis. Sub-hypotheses 1 and 2 (see paragraph 1.4) serve as theoretical propositions for this research.

The research design must assist in the generalisation of the results and therefore the theory. Yin (2009:38) describes analytic generalisation where “previously developed theory is used as a template with which to compare the empirical results of the case study”. He states (Yin, 2012:18) that “analytic generalisations depend on using a study’s theoretical framework to establish a logic that might be applicable to other situations”. Generalisation claims can be strengthened by demonstrating that a theory is supported in more than one case, or where a rival theory is shown not to be valid or, even better, where both claims are demonstrated (Yin, 2009:39).

Stake (1995:7-8) is more reticent about inferring generalisation, stating “case study seems a poor basis for generalisation” and “the real business of case study is particularisation, not generalisation”. He nevertheless refers to triangulation as a procedure to improve the validity of claims of generalisation.

Yin (2009:40-43) described in detail four criteria for judging the quality of research designs. *Construct validity* refers to choice and applicability of the data sourced to logically and coherently come to conclusions. *Internal validity* refers to that data analysis stage of research where cause and effect, in the case of explanatory case studies, and generally the solidity of evidence to support inferences, are made. *External validity* refers to the extrapolations, or generalisations that can be made, while *reliability* refers to the data collection stage and the repeatability of a study.

Case study research is particularly appropriate when a *descriptive* question – "What is happening or has happened" – or an *explanatory* question – "How or why has something happened" needs to be answered (Yin 2009:5).

Mouton (2001:144) provides a two-dimensional depiction with the X-axis contrasting empirical vs. non-empirical data and the Y-axis primary vs. existing data as shown in adapted form in Figure 3-1. He also provides a classification consisting of twenty-two research design types using these as well as two further dimensions, being "data types" and "degree of control" (2001:150-180). Although not a perfect fit, the case study data that are addressed in the first part of the research design can be compared to Mouton's type 2, "ethnographic research: case studies" (2001:149-150), which falls in the third quadrant of Figure 3-1, "secondary data analysis". The second part of this research relates to Mouton's type 20, "theory building and model-building studies" (2001:176-177), and fits into the first and fourth quadrants as shown.

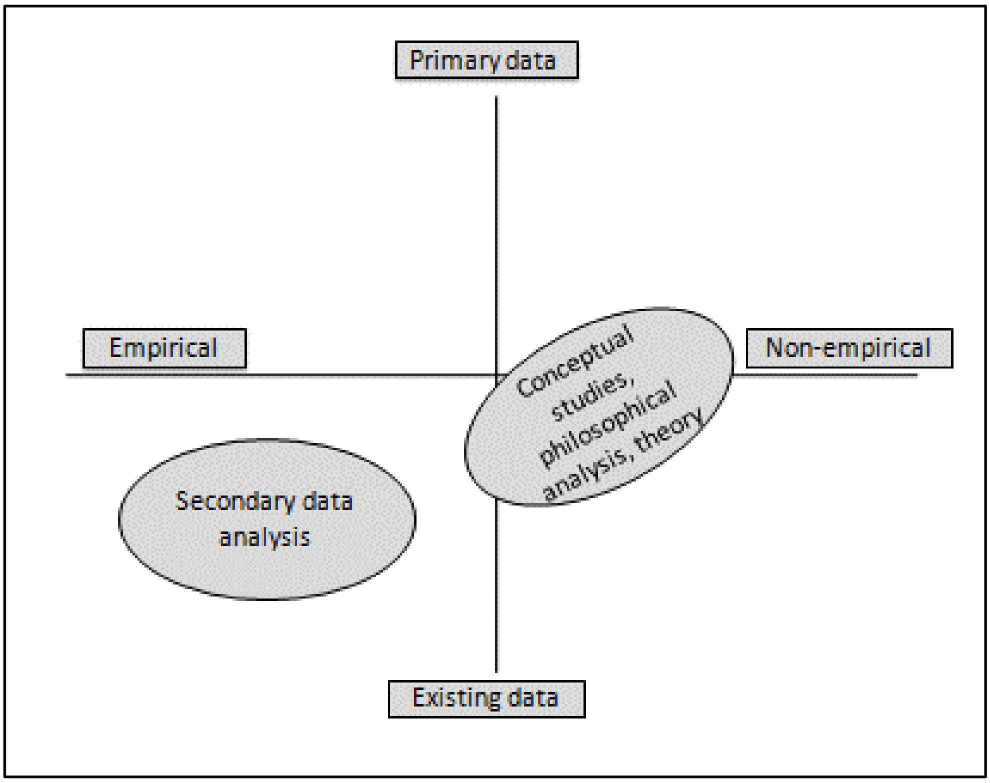

Figure 3-1: Research Mapping

To summarise: this research comprises (a) case study research and secondary data analysis to address the first two research questions – the first being explanatory and the second descriptive – and (b) conceptual analysis to address the third and fourth research questions.

3.2 Investigation into causes of mismatches between projected and actual water transfers and implications for the Incremental Approach

This part of the research addressed the theoretical proposition of sub-hypothesis 1, *The Incremental Approach of IBT project appraisal does not adequately consider receiving catchment conditions and a comprehensive systems simulation is required at project appraisal stage if variable costs (e.g. pumping costs) are associated with water transfers.*

The research question, *Why are there differences between the projections of water transfers at the planning stage and the actual transfers after implementation of an IBT and do these differences indicate an inadequacy of the Incremental Approach (IA) of project appraisal?"* was addressed by undertaking explanatory case study research to identify causal links (Yin, 2009:19 and Stake, 1995:38).

While the provisional observations (see par 1.1.2) related to the Usutu-Vaal IBT pointed at transfer characteristics quite different from those envisaged during their planning phases, these are examined further regarding other factors that may have impacted on the quantities transferred, such as possible water shortages in the source catchments, and differences in growth in demand from what was foreseen at the initial planning stage.

With the focus on one main case study, an "intensive approach" as described by Swanborn (2010:2) is followed. An in-depth analysis of the historic water transfer data of the Usutu-Vaal GWS was undertaken and the characteristics of water transfers of this IBT compared with that originally predicted at the appraisal stage. Differences in characteristics and whether a consistent bias was indicated were examined, as well as the role fulfilled by this IBT from a comprehensive systems perspective.

Further proof of the mismatch between projected and actual water transfers, and the causal effect thereof, is obtained by an in-depth analysis of 22 years of annual operating analyses as recorded.

Construct validity was ensured by obtaining data that measured shifts and could be descriptively correlated to establish a chain of evidence whilst *internal validity* was attended to by motivation of the causal relationships (Yin, 2009:40-42) as well as the *triangulation* presented by viewing the phenomenon from the operational perspective.

Further confirmation was obtained from a similar analysis of the Tugela-Vaal GWP, providing external validity to the research design.

3.3 An assessment of possible changes in appraisal methodology since the availability of probabilistic simulation tools

The theoretical proposition that "the Incremental Approach is generally being applied in the appraisal of IBT projects" is analysed here. The second research question: *"How generally is the IA applied?"* lends itself to a descriptive case study research method, as described by Yin (2009:20, 36) which, within the "descriptive mode", could illustrate whether the proposition is supported.

The expectation has been that this review would show empirically that the methodologies currently employed to appraise IBTs in South Africa do not differ materially from those in the earlier studies though far more sophisticated systems analysis tools were used to assess the yield contributions of such projects.

In order to provide "*construct validity*" (Yin 2009: 40-41) to the design, project reports and literature on a selection of appraisals conducted in recent years are analysed with the aim of identifying, categorising and comparing methodologies employed. These multiple case studies were also chosen with a representative spread of professional service providers in South Africa in mind. In addition, two case studies beyond the borders of South Africa, an appraisal by the World Bank of the Wanjiazhai Water Transfer Project in China, and an appraisal of options to augment water supplies for Brisbane in South East Queensland, Australia, were included to ascertain whether the appraisal methodology applied there had similarities to the Incremental Approach.

Internal validity (Yin 2009:42) is tested by checking convergence of the evidence from the cases studied.

3.4 From the Incremental Approach to an improved Comprehensive Approach

In this section the steps to improve upon the Incremental Approach are proposed as a result of this research. The new approach suggested is called the Comprehensive Approach.

3.4.1 Simulating the whole system and determining the probabilistic characteristics of water transfers

By means of an example it is shown that an integrated simulation of the system, of which the proposed IBT project is an integral part, is required to obtain water transfer characteristics similar to those witnessed in practice. The elements of the Incremental Model that are affected are shown in Figure 3-2.

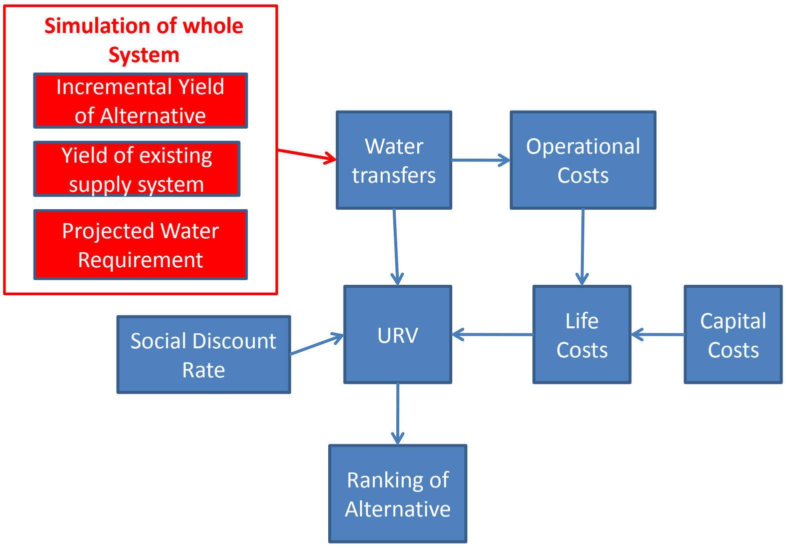

Figure 3-2: Towards a Comprehensive Approach: Introducing integrated system simulation

As a first step a process is introduced whereby, with the introduction of stochastic hydrological data as input to an integrated simulation model, repeated a suitable number of times, the probability distribution of monthly water transfers that can be expected from the future operation of the proposed IBT is obtained (see elements affected in Figure 3-3).

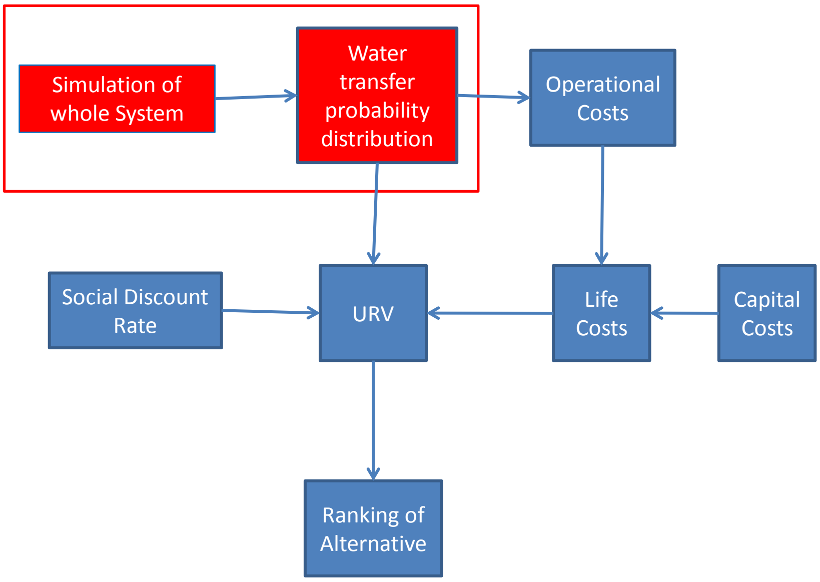

Figure 3-3: Towards a Comprehensive Approach: Introducing uncertainty of water transfers

3.4.2 Estimation of appropriate present value of water transfers and operational costs

The next step proposed, leading towards a Comprehensive Approach, involves the estimation of the appropriate present value of water transfers and the determination of the present value of the associated variable operational cost. Using decision analysis theory the process to establish an unbiased present value is demonstrated. The elements of the Incremental Approach affected are shown in Figure 3-4.

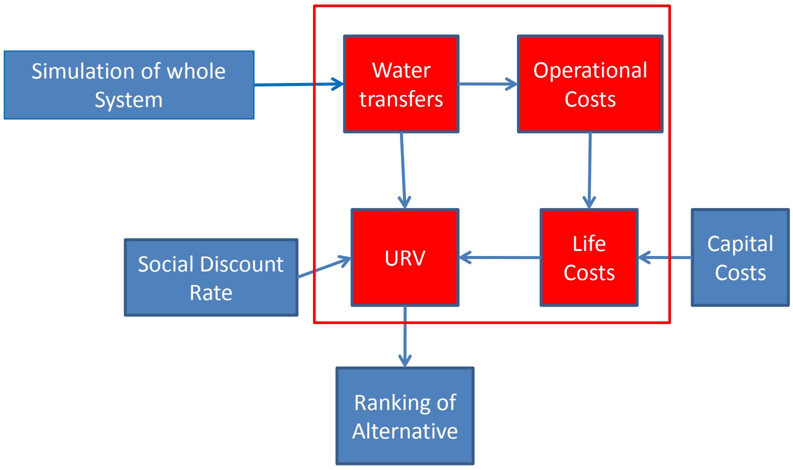

Figure 3-4: Towards a Comprehensive Approach: Elements affected by reassessment of water transfer characteristics

3.4.3 Rooting the Unit Reference Value (URV) in economic theory

A conceptual study was undertaken to ascertain whether the theoretical proposition of *sub-hypothesis 3,* that “The URV method to derive the relative economic viability of an IBT project, and which forms part of the Incremental Approach, requires greater conceptual clarity” was supported, and to respond to research question 4, “How must the URV methodology consequently be improved?”

This step comprised rooting the URV measure in the theory of the economics of cost-effectiveness analysis (CEA), through a fundamental philosophical analysis. New factors were identified to assist in an improved assessment of the effectiveness of the proposed IBT projects. These were then considered for inclusion in the URV calculation, as highlighted in Figure 3-5.

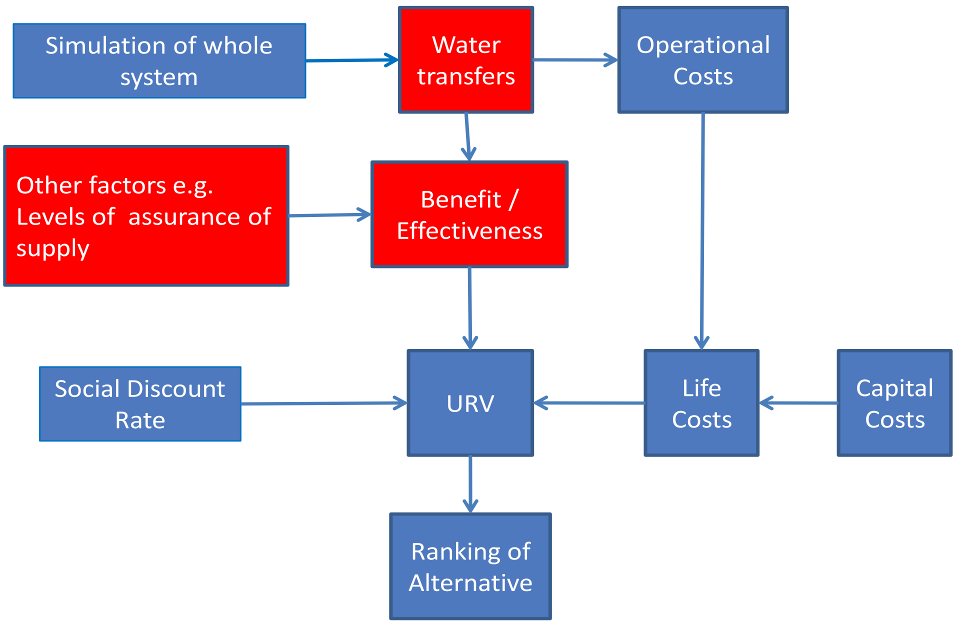

Figure 3-5: Towards a Comprehensive Approach: Inclusion of effectiveness in the URV

3.5 Demonstrating the application and value of the Comprehensive Approach

The application of the Comprehensive Approach, as a result of this research, is demonstrated by applying it to a recently completed study which compared the implementation of a proposed second phase of the Lesotho Highlands Water Project (LHWP) against a possible next phase of importing water from the Thukela River, the latter being an IBT project with significant pumping costs. It is shown that the Comprehensive Approach can lead to significantly different results than the Incremental Approach, which could affect the ranking of an IBT project. Such differences may affect a final implementation decision and consequently have a considerable economic implication.

4 Causes of mismatches between projected and actual water transfers

The purpose of this chapter is to examine the differences between actual water transfers of an IBT scheme and original projections at the time the planning of the project, and to draw inferences regarding the Incremental Approach.

4.1 Introduction

It is important at the planning stage to have a realistic estimation of the volumes of water likely to be transferred in the future. This is especially so when significant pumping costs are involved (which is often the case with IBTs) as the choice of a project, and its configuration, is likely to be influenced by these (variable) costs.

A number of IBTs have been in operation in South Africa for some time. Two were selected as case studies for further examination: the Usutu-Vaal River GWS being typical, and with data records readily available, and the Tugela-Vaal GWP, with its important support to the Vaal River System.

4.2 Review of historic water transfer data of the Usutu-Vaal GWS (Second Phase) and comparison

This section describes actual water transfers of the Usutu-Vaal GWS (Second Phase) and compares these to the characteristics predicted at the appraisal stage.

4.2.1 Description and background

The growth of coal-based industries on the Eastern Highveld with their associated water demands necessitated a decision in 1981 to build a scheme to transfer water from the Usutu River Basin to the Vaal River Basin. This was the second phase of the Usutu-Vaal River GWS which consisted of the Heyshope Dam in the Assegai River (a tributary of the Usutu River), a pumping station to deliver water against a 193 meter static head, and a canal to transport the water into the upper reaches of the Little Vaal River, a tributary of the Vaal River (Department of Water Affairs, Forestry and Environmental Conservation[3], 1981:3). This project followed the first phase of the GWS, comprising the Grootdraai Dam in the Vaal River near the town Standerton and its aqueduct which transferred water to the Eskom power stations and the SASOL fuel-from-coal-based plant in the upper Olifants River catchment (DWA, 1976:3). Figure 4-1 shows these locations (as well as other projects and locations that are mentioned later).

[3] In the 1980s the Department of Water Affairs was absorbed, for a short period, into a new Department of Water Affairs, Forestry and Environmental Conservation, subsequently renamed the Department of Environment Affairs.

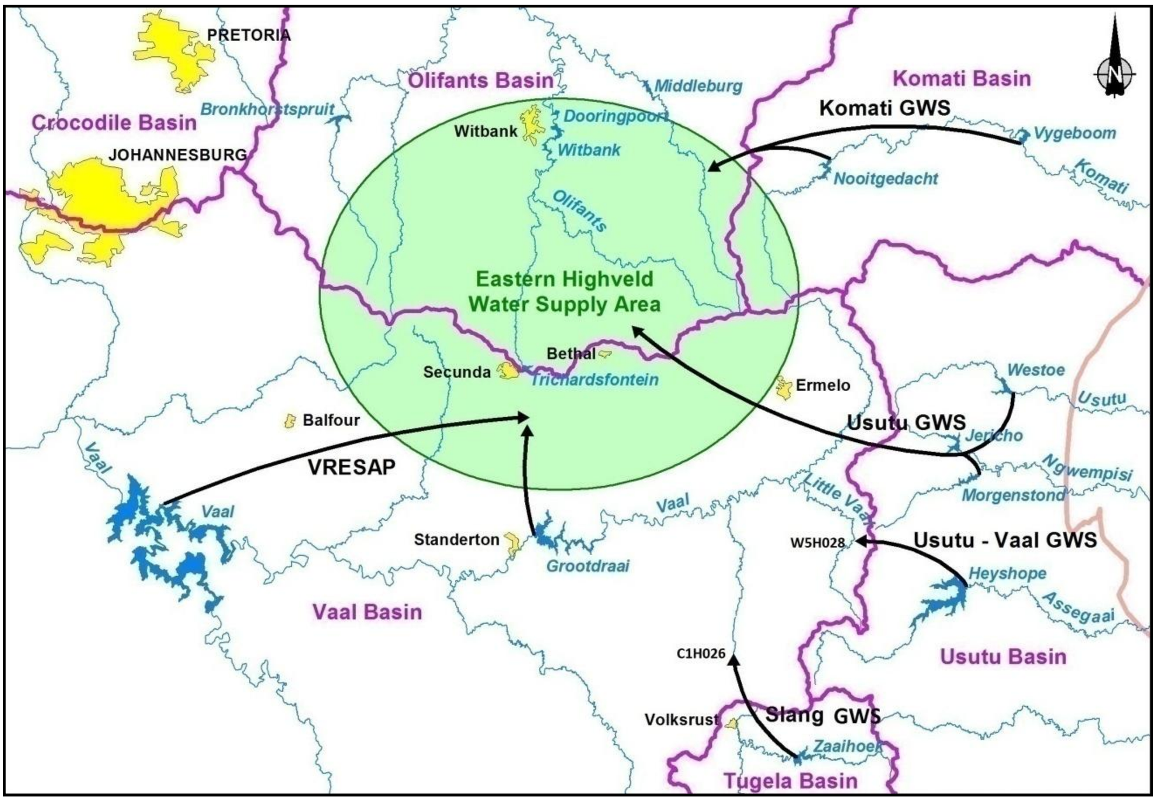

Figure 4-1: The upper Vaal River system and related IBTs

The water demand of the SASOL 2 and 3 facilities was projected to reach 73 million m^3/a by 1982 and, with secondary industries, the ultimate demand was estimated at 80.3 million m^3/a (Department of Water Affairs, Forestry and Environmental Conservation, 1981:5). The total demand, including water losses, reliant on the two phases of the Usutu-Vaal River GWS was projected to reach 627.8 thousand m^3/d, i.e. 229 million m^3/a, by the year 1995 (1981:8).

The "net sustainable yield" of the Grootdraai Dam, after allowing for downstream obligations of river releases, was estimated at 160.5 million m^3/a (DWA, 1976:11). Of this, 6 million m^3/a was required downstream for the town Standerton and irrigation between Grootdraai Dam and Vaal Dam. The remainder of the yield was available for new uses.

The net yield contribution by the second phase of Usutu-Vaal scheme was estimated at 99.7 million m^3/a (Department of Water Affairs, Forestry and Environmental Conservation, 1981:10). In the White Paper that proposed the project, the transfers from the Usutu basin to the Vaal basin were projected to increase steadily until the maximum available quantity for transfer of 99.7 million m^3/a had been reached by the (financial) year 2000/01 (1981:17). The estimated incremental yield was later revised to 121 million m^3/a (RSA, Department of Environment Affairs, 1984:6).

Figure 4-2 illustrates the 1981 estimated growth of water demand, the estimated yields at the time of the two phases of the Usutu-Vaal River GWS and the inter-basin transfers as projected.

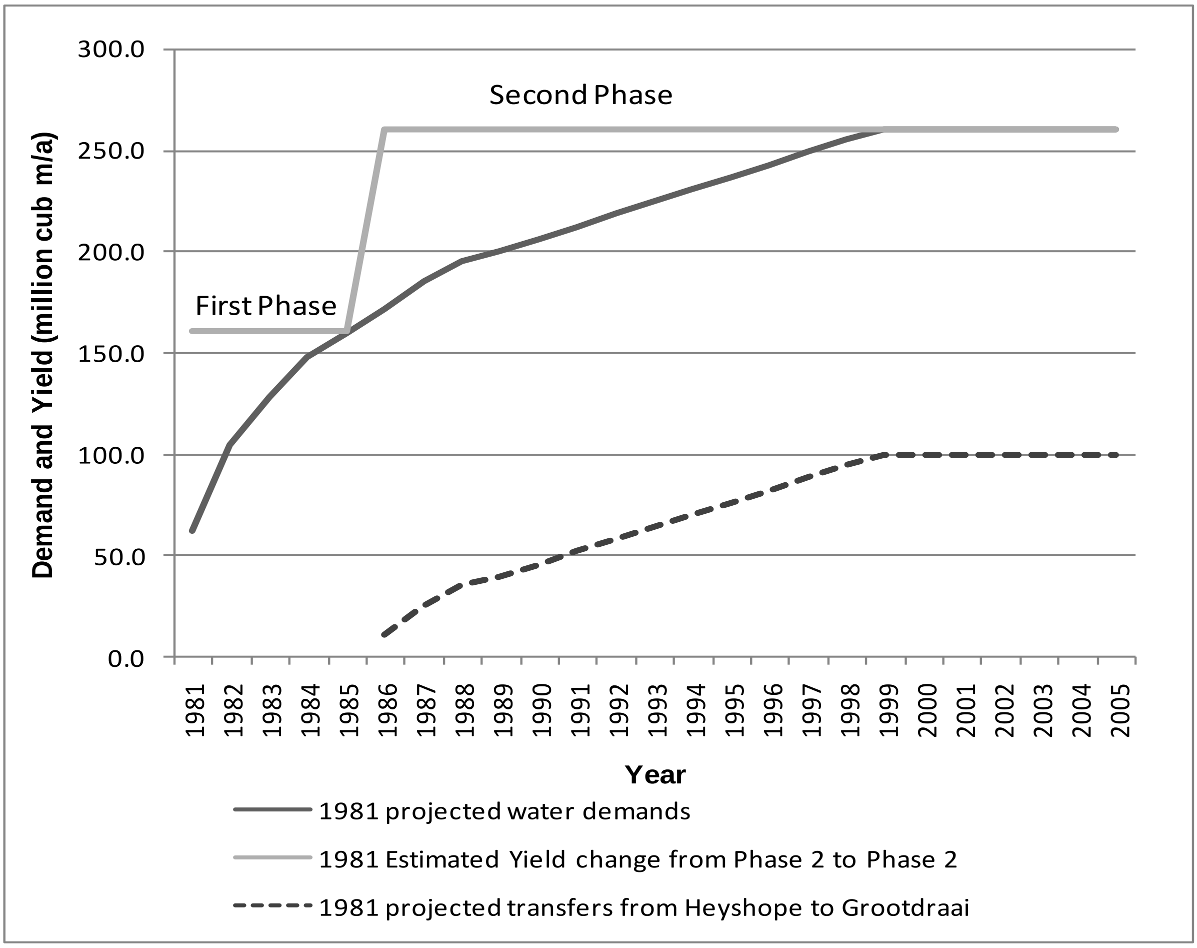

Figure 4-2: Usutu-Vaal River GWS: 1981 projected requirements, transfers and yield increase

It follows from the description above that the approach during the planning of the Usutu-Vaal River GWS typified the Incremental Approach described in Chapter 1. The incremental demand at Grootdraai Dam had been assumed would be met solely by water transfers from the planned scheme. This reflected too in the cost analysis as the pumping costs were related directly to these assumed transfers (Department of Water Affairs, Forestry and Environmental Conservation, 1981:17).

4.2.2 Actual transfers since construction of the Usutu-Vaal River GWS

The actual volumes of water transferred to the Little Vaal River from the Usutu Basin, as recorded by the Department of Water Affairs at gauge W5H028, were obtained for the 24 (hydrological) years from 1985/6 to 2009/10. These are graphically illustrated in Figure 4-3 against the transfers envisaged in White Paper (WP) F-'81 (Department of Water Affairs, Forestry and Environmental Conservation, 1981:17).

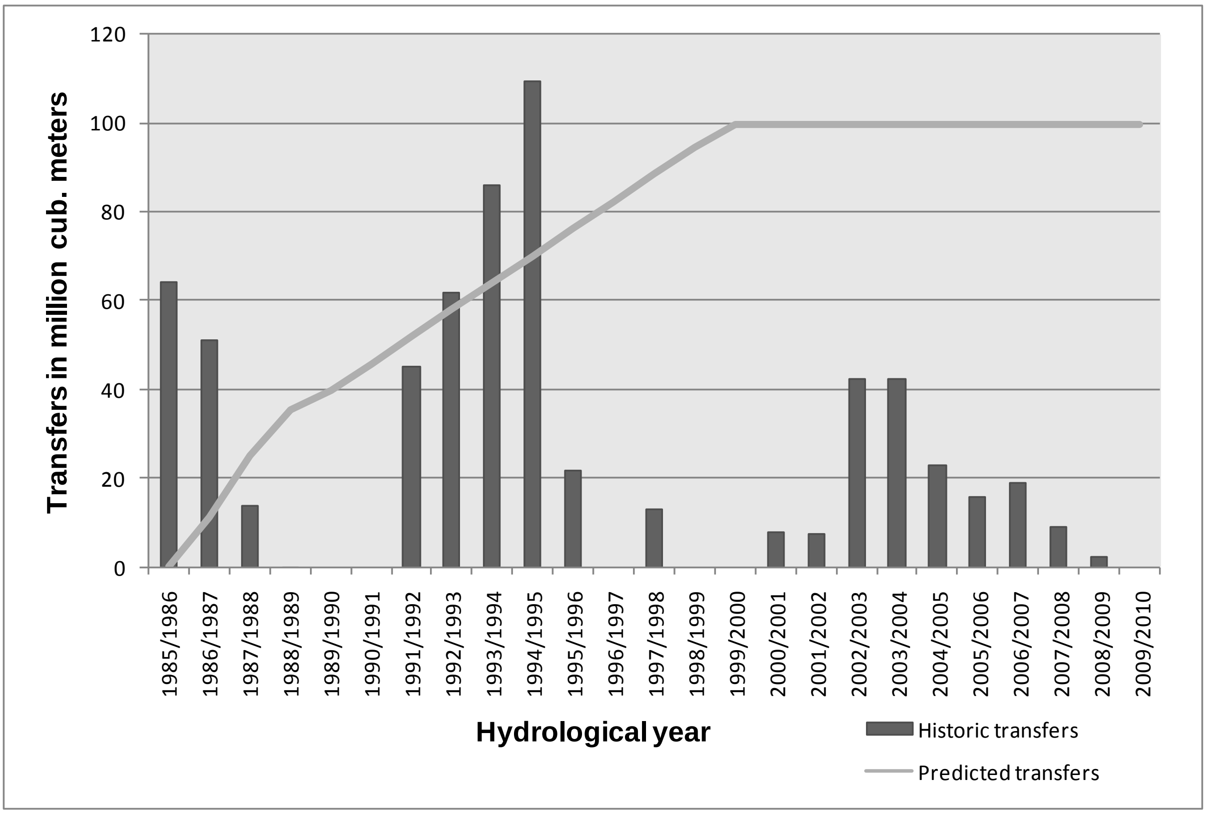

Figure 4-3: Usutu-Vaal GWS (Second Phase): Historic transfer volumes against transfers predicted in WP F-'81

It should be noted that some modifications were made to the supply system in 1987 to also divert (emergency) water from the transfer canal to the Usutu GWS, a separate (and older) system linking the three dams, Jericho, Morgenstond and Westoe (see localities in Figure 4-1) to the Camden, Kriel and Matla power stations on the Eastern Highveld. Care was thus taken only to investigate transfers to the Little Vaal River.

The result showed a very different picture from what had been forecasted in WP F-'81; the pattern of the transfers had not been gradual, but erratic, and the average transfer was 25.5 million m^3/a over the past 24 years, or only some 25% of what had been envisaged at the planning stage. The large transfers in the 1980s and 1990s coincided with droughts in the Vaal River system as shown later in par. 4.2.10.

4.2.3 Need for investigation

Any over-estimation of water transfer quantities at the planning stage, where decisions have to be made as to the configurations of projects, could have significant financial and water resource management consequences. If pumping costs, for instance, are over-estimated there would be a bias against projects involving pumping of water. The reason for the differences found between the expected and actual transfers in the case of the Usutu-Vaal River GWS should be further investigated. The following sections therefore examine the impact of other resource development, possible changes in actual growth in demand, possible variability in demand, and possible constraints in water supply as a result of drought in the source catchment.

4.2.4 Augmentation from the Slang River

For only a short period had the Usutu-Vaal River GWS been the only IBT to augment the water resources of the Grootdraai Dam subsystem: in 1988 the Zaaihoek Dam was completed near Volksrust on the Slang River, a tributary of the Buffalo River (see Figure 4-1), which in turn is a major tributary of the Thukela River. The Slang River GWS (Zaaihoek Dam) was built specifically to serve the Majuba Power Station and its coal mine in the vicinity of the town Amersfoort, but the conveyance system crossed the Perdewaterspruit, a tributary of the Skulpspruit which flowed into the Vaal River. The facility was also included to release water into the Perdewaterspruit to augment the Grootdraai Dam subsystem and, until 1996 as well, the rest of the Vaal River System (DWA, 1986:1).

The introduction of the transfer from the Zaaihoek Dam to the Grootdraai Dam subsystem increased the “dependable yield”, as it was called, from 252 million m^3/a to 319 million m^3/a (DWA, 1986:8). (Note that the 252 million m^3/a yield was a reduction of the 1984 estimation of 281 million m^3/a[4], probably due to a reassessment after the severe drought of the early 1980s.) The water requirement from the Usutu-Vaal River GWS (Grootdraai Dam) (1986:7), as projected in the White Paper, is shown graphically in Figure 4-4.

[4] It is assumed that these yields were determined from historical records, i.e. equivalent to historic firm yields (HFY) – the term used today.

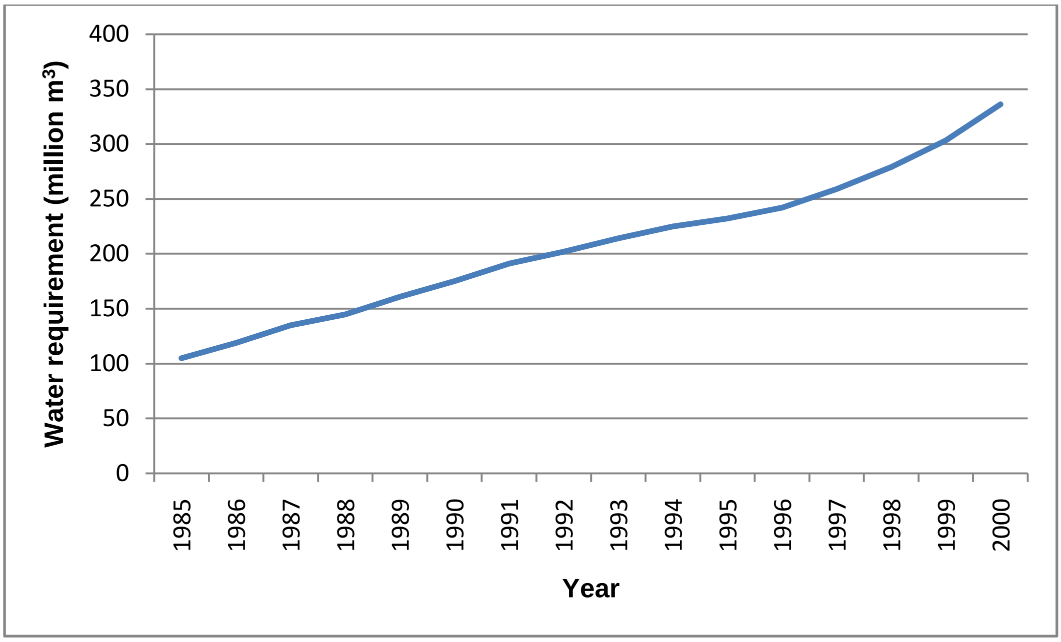

Figure 4-4: 1986 projection of water requirements from the Usutu-Vaal River GWS (Grootdraai Dam)

It was recognised at the time that augmentation of the Grootdraai sub-system by means of the transfers from the Slang River GWS (Zaaihoek Dam) was required only after 1996 but that the rest of the Vaal System could benefit until then by the export of the "surplus water" (DWA, 1986:8).

The annual releases as measured at gauge C1H026 (Figure 4-1) in the Perdewaterspruit are shown in Figure 4-5. The average transfer from this source was 22.5 million m^3/a over the period 1990 to 2010.

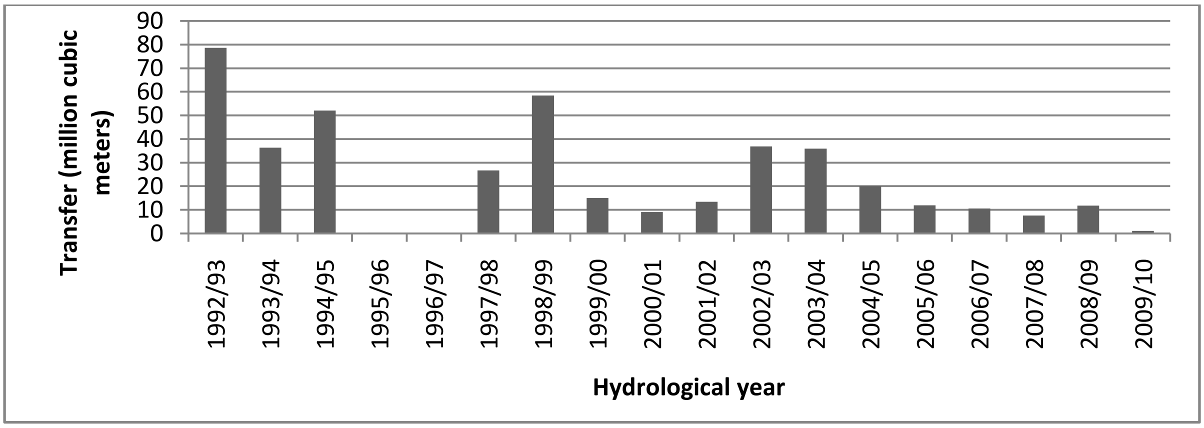

Figure 4-5: Slang River GWS: Historic transfer volumes at Skulpspruit outlet (C1H026)

4.2.5 Combined transfers from Usutu-Vaal River GWS (Heyshope Dam) and the Slang River GWS (Zaaihoek Dam)

To obtain a more complete view of inter-basin transfers into the Grootdraai Dam subsystem the transfers from the two sources, the Usutu basin as the Slang River, are combined as shown in Figure 4-6. Again these are compared to the transfers as predicted in White Paper F-'81 (Department of Water Affairs, Forestry and Environmental Conservation, 1981:17).

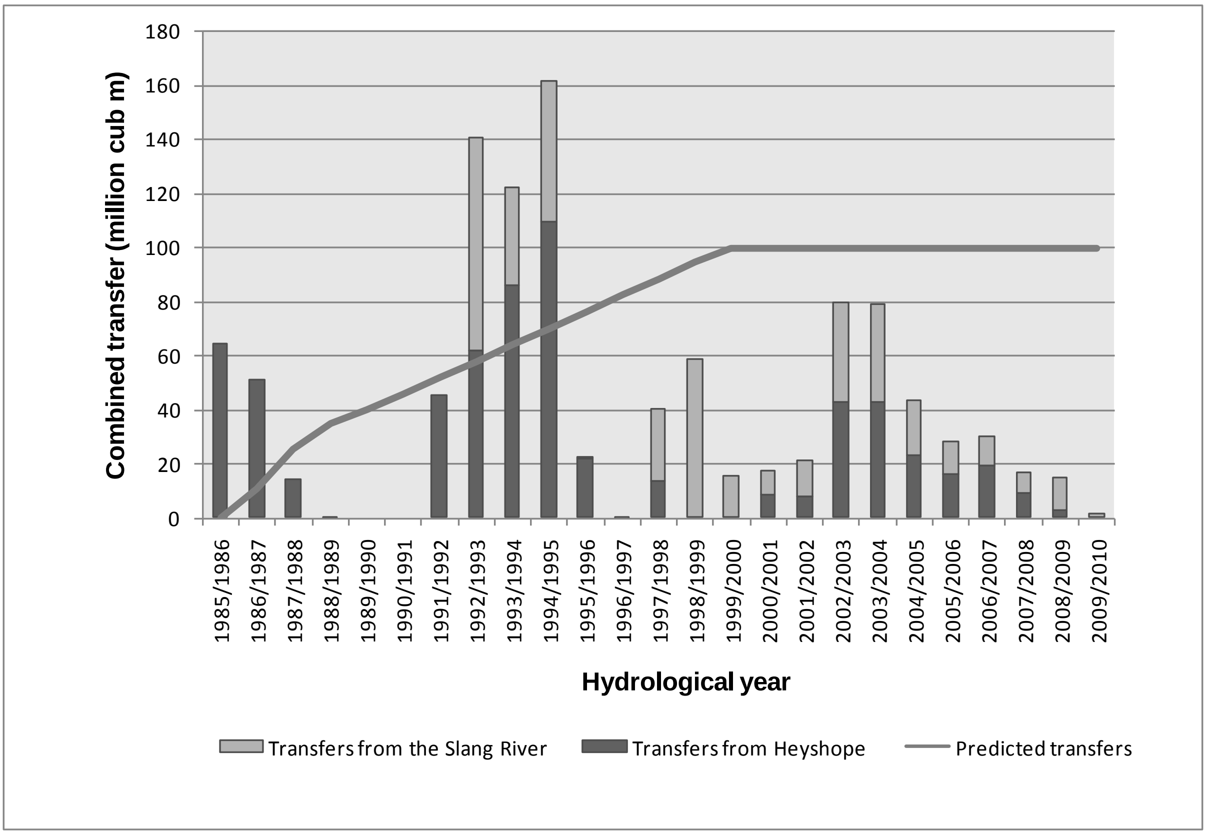

Figure 4-6: Combined historic transfers from the Usutu-Vaal River GWS and the Slang River GWS to the Upper Vaal compared to transfers predicted in WP F-'81

It can be seen that the transfers into the Grootdraai Dam catchment varied significantly from year to year over the period. As shown in the storage level graph of Grootdraai Dam (Figure 4-7 below), the Grootdraai subsystem experienced a drought over the period 1991/2 to 1993/4. During the latter part of this period the historic transfers from the Usutu-Vaal River GWS and the Slang River GWS were at their highest, initially with the latter GWS contributing most water, but with the Usutu-Vaal River GWS taking over during the later part of the drought.

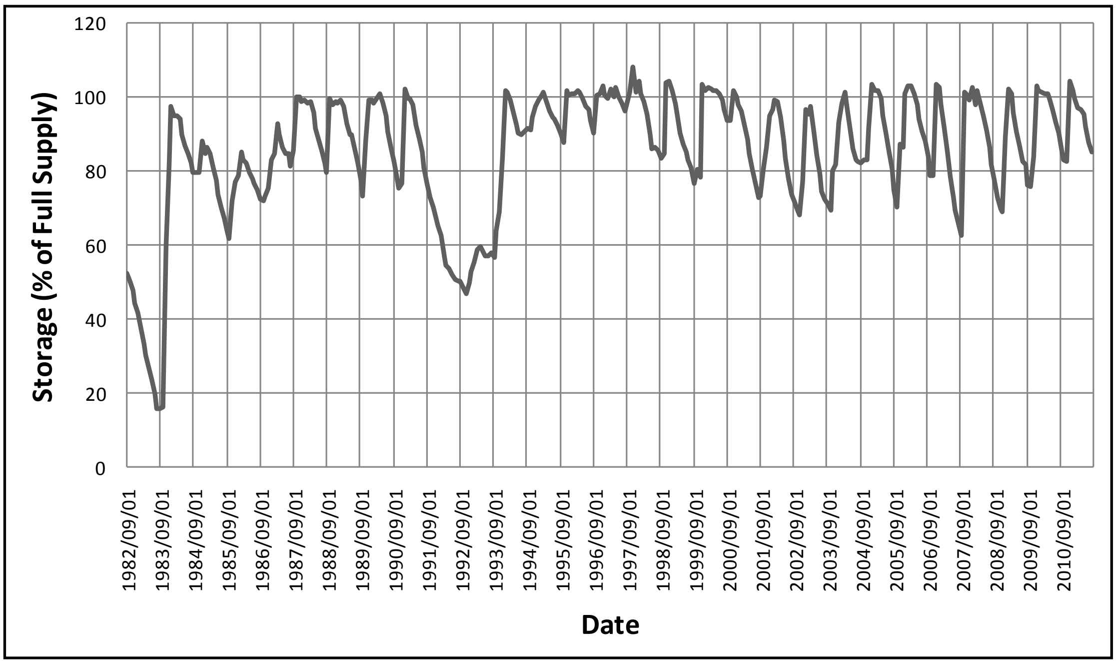

Figure 4-7: Grootdraai Dam storage levels

Combining the two transfer records does not lead to a transfer record with significantly different characteristics than that of the individual two records. It also does not explain why the projected transfers during the planning stage differed so significantly from what was actually experienced.

4.2.6 The VRESAP: Augmentation from Vaal Dam

It needs to be noted that a recently completed transfer scheme, the Vaal River Eastern Subsystem Augmentation Project (VRESAP), started delivering water in 2009. This project conveys water from the Vaal dam via a 121-km pipeline to Knoppiesfontein near Secunda where it is connected to the existing infrastructure of the Usutu-Vaal River GWS.

The VRESAP was undertaken to provide improved assurance of water supply to the Eskom and Sasol facilities on the Highveld as system yield analyses found the re-estimated level of assurance to these strategic industries to be inadequate. It also provided additional security against possible failure of the Vlakfontein canal that had been the sole link to the resource for Sasol and a large part of the demand of Eskom.

The actual quantities of water transferred by the VRESAP to date have been for testing purposes only. The quantities supplied thus far were not significant for purposes of this review, but in future, when reconstructing actual water demand, would need to be taken into account.

4.2.7 Actual water demand

An additional issue to be investigated is whether the water demand occurred as predicted. The record of abstraction from Grootdraai Dam on the Vaal River (hydrological station C1R002) was examined. Records were obtained for the G27 component, the transfer via the Vlakfontein Canal to the SASOL coal to fuel facility plus the Eskom power stations Matla, Duvha, Kendal and Kriel (all four of which also receive water – preferentially - from other subsystems) and the transfer via a separate pipeline to Eskom's Tutuka power station, the G28 component of the record.

To the total of the above two records were added the compensatory river releases from Grootdraai Dam. While these releases were originally envisaged to be only 6 million m^3/a (see par. 4.2.1), the operating rule applied by DWA subsequently allowed for a release of 20 million m^3/a (Swart, 2011a). The total water requirement from Grootdraai Dam, with and without compensation releases, is depicted in Figure 4-8.

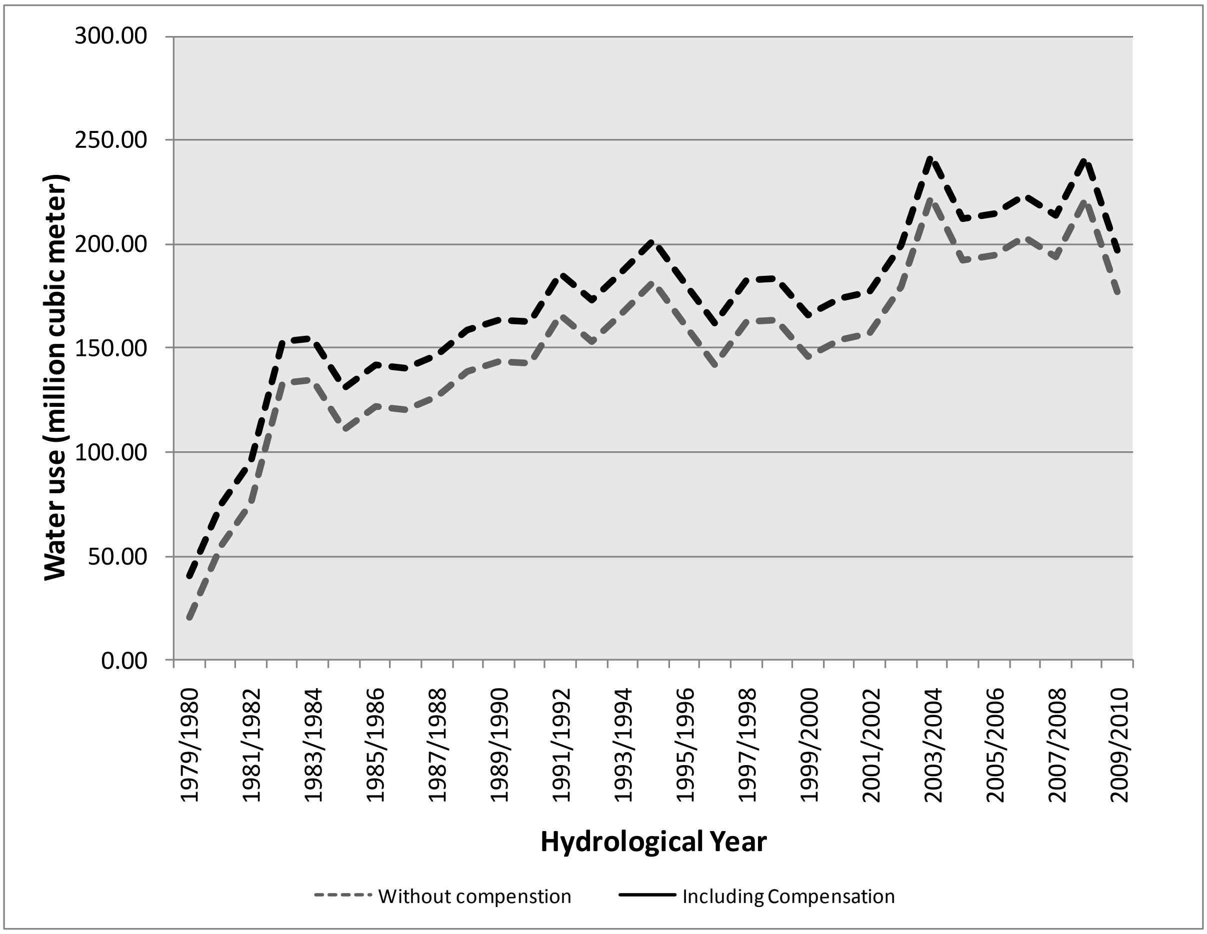

Figure 4-8: Water use from the Usutu-Vaal River GWS (Grootdraai Dam)

As mentioned above, some of the Eskom power stations are served preferentially from other resources, these being the Usutu GWS and the Komati GWS. This would largely explain the variability around the trend observed in Figure 4-8, as the water use by SASOL was relatively stable between 84 and 90 million m^3/a since 2001 (Swart, 2011b).

It is therefore concluded that, after an initial rapid increase, the growth in water use from the Usutu-Vaal River GWS (Grootdraai Dam) was slower than envisaged in 1981 (shown in Figure 4-2). This may point to an explanation as to why the transfer from the Heyshope Dam was only some 25% of what was envisaged during the original planning stage. The question does arise then, too, why it was necessary to add further sources to the system, viz. the Slang River GWS and the VRESAP. This requires the examination of investigations into the yield of the system subsequent to the planning of the Usutu-Vaal River GWS (Phase 2).

4.2.8 Yield estimations

Since the 1976 estimate of the "net sustainable yield" of the Grootdraai Dam of 160.5 million m^3/a, further yield analyses of all the sub-systems of the Vaal River System were undertaken. This was required as a severe drought in the early 1980s affected all the sub-systems. Improved computational ability and advanced system modelling techniques were employed. Generally it was found that the sub-systems had significantly lower historical firm yields (DWAF, 2001b:3-47).

The results for Grootdraai Dam, as well as Heyshope Dam, are shown in Table 4-1.

Table 4-1: Yield estimates of the Grootdraai and Heyshope Dams (all units in million m^3/a)

Dam	Original Yield estimate	Historical firm yield estimate in 2001	2001 long-term stochastic yield estimates (at indicated recurrence intervals)			
			1:20 year	1:50 year	1:100 year	1: 200 year
Grootdraai	160.5	124	180	151	130	118
Heyshope	104.9	59	73	63	58	53

The long term stochastic yields showed an average reduction, on what had been earlier estimated, of 19% for Grootdraai Dam and 28% for the Heyshope Dam. Only the yield of the Zaaihoek Dam was found to have increased by 10%. The historical firm yield for the total integrated Vaal River System had reduced by 23% (DWAF, 2001b:3-47). While an integrated systems analysis for the sub-system of the Grootdraai Dam, plus the transfers from the Heyshope and Zaaihoek dams, had not been undertaken during that investigation, it may be reasonable to assume that the 1986 quoted "dependable yield" of the subsystem of 319 million m^3/a (mentioned earlier) (DWA, 1986:7) can be reduced by a similar percentage, which would give a comparative firm yield of some 250 million m^3/a.

Table 4-2 summarises the revisions over the years of the yield of the Grootdraai Dam system.

Table 4-2: Sequence of firm yield estimates for the Grootdraai Dam system

Year of estimate	Firm yield estimation (million m^3/a)	Description
1976	161.5	Grootdraai Dam
1981	251.2	99.7 million m^3/a added by Usutu-Vaal River GWS (Heyshope Dam)
1984	282.5	121 million m^3/a added by Usutu-Vaal River GWS (revised estimate)
1986	252	Revised estimate
1986	319	Adding transfer from the Slang River GWS (Zaaihoek Dam)
2001	250	Revised estimate

Comparing the yields from Table 4-2 with the actual requirements in Figure 4-8 shows that the system requirements had been close to its firm yield since 2004. This would explain the need for the augmentation for which the VRESAP scheme was recently undertaken.

4.2.9 Heyshope Dam record

Another factor that could influence the quantities of water transferred from the Usutu River to the Vaal River, besides growth in requirement that may not have materialised, may have been that there was a shortage of water in Heyshope Dam – the source of water for the transfer. This was investigated by obtaining the recorded dam levels (DWA hydrologic record W5R004) for the period 1 January 1986 to 1 March 2011. Figure 4-9 shows that, after its first filling, the Heyshope Dam was close to full capacity for most of the time. The lowest level recorded was 41% in December 1995, indicating that there had been no impediment, from a source perspective, in transferring water to the Vaal Basin.

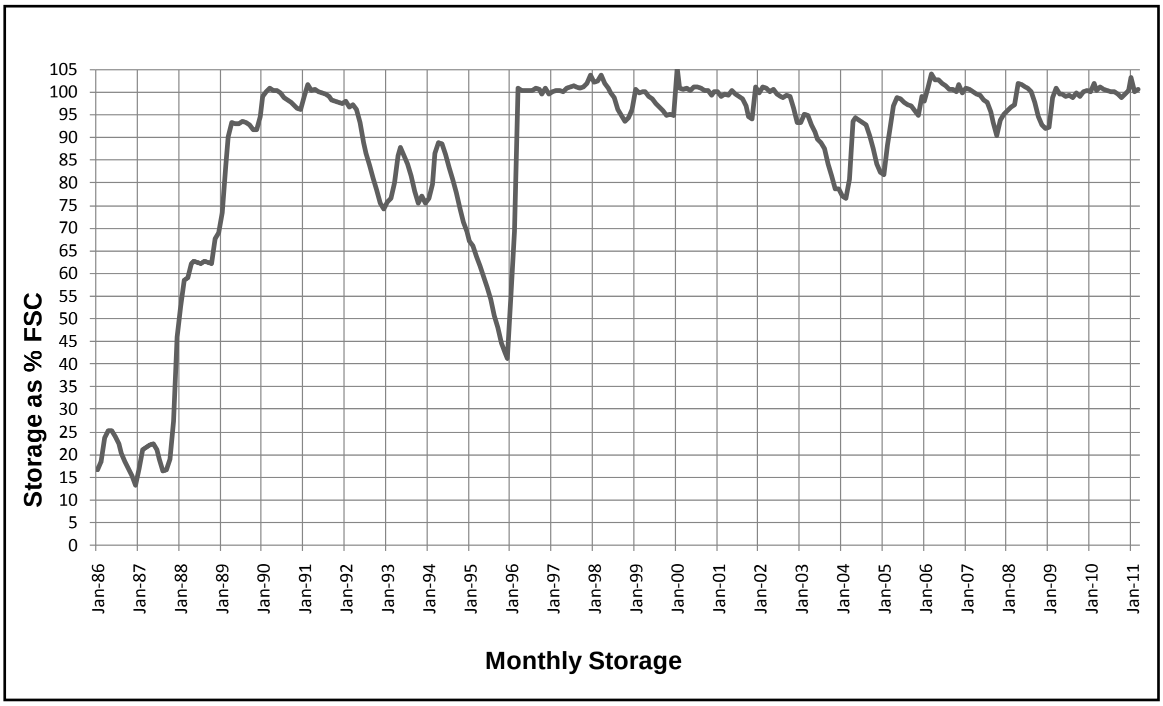

Figure 4-9: Heyshope Dam (W5R004) Storage from January 1986 to January 2011

4.2.10 Discussion

While the growth in demand was lower than envisaged in 1981, the available system yield estimates reduced substantially since then – to the extent that an expensive scheme, the VRESAP, was built to ensure the strategic coal-based industries of a secure supply of water. The situation therefore never arose that the whole system was considered to have a yield greatly in excess of demand and, therefore, that water transfers from the Heyshope Dam were not required. However, as the actual use had been lower than envisaged in 1981, it would be reasonable to expect that the transfers would also have been less. The transfers from the two IBTs, the Heyshope Dam and Zaaihoek Dam, combined, should be compared to the actual water use in excess of the Grootdraai Dam yield, without the IBTs. As shown in Table 4-2, this latter yield of the Grootdraai Dam reduced from 160.5 million m^3/a to 124 million m^3/a between1981 and 2001.

By analogy, the same methodology can be followed as had been used originally in the planning of the Usutu-Vaal River GWS in 1981, as though stepping back in time but having accurate knowledge of future demands. Thereby all demands, beyond the 124 million m^3/a that Grootdraai Dam could have delivered securely, had to be met by the transfers from the two IBT projects. This resulted in an average transfer over the 25 year period (from 1985/6 to 2009/10) of 61.4 million m^3/a. Moving forward to present time, this result is compared to the actual (combined) average transfer of 42.5 million m^3/a, as had been recorded, which is found to be about 30% lower than the “planned” requirement of 61.4 million m^3/a (see

ANNEXURE 4-A for detail). It can therefore be concluded that applying the 1981 methodology would have led to an overestimation of 45% of the volume of water to be transferred.

Because one of the objectives of the Slang River GWS was also to augment the Vaal River system below Grootdraai Dam (as mentioned in par. 4.2.4), a check was undertaken as to whether a portion of the transfers from the Slang River, especially in its earlier years where large volumes were transferred (as can be seen in Figure 4-5), passed through to Vaal Dam. Grootdraai Dam reached a low of about 50% of its full supply level (FSL) during the drought in the early 1990s (see Figure 4-7) but the storage of the Upper Vaal, which included the large Vaal and Sterkfontein Dams, reached an even lower level of 35% during that drought, as shown in Figure 4-10.

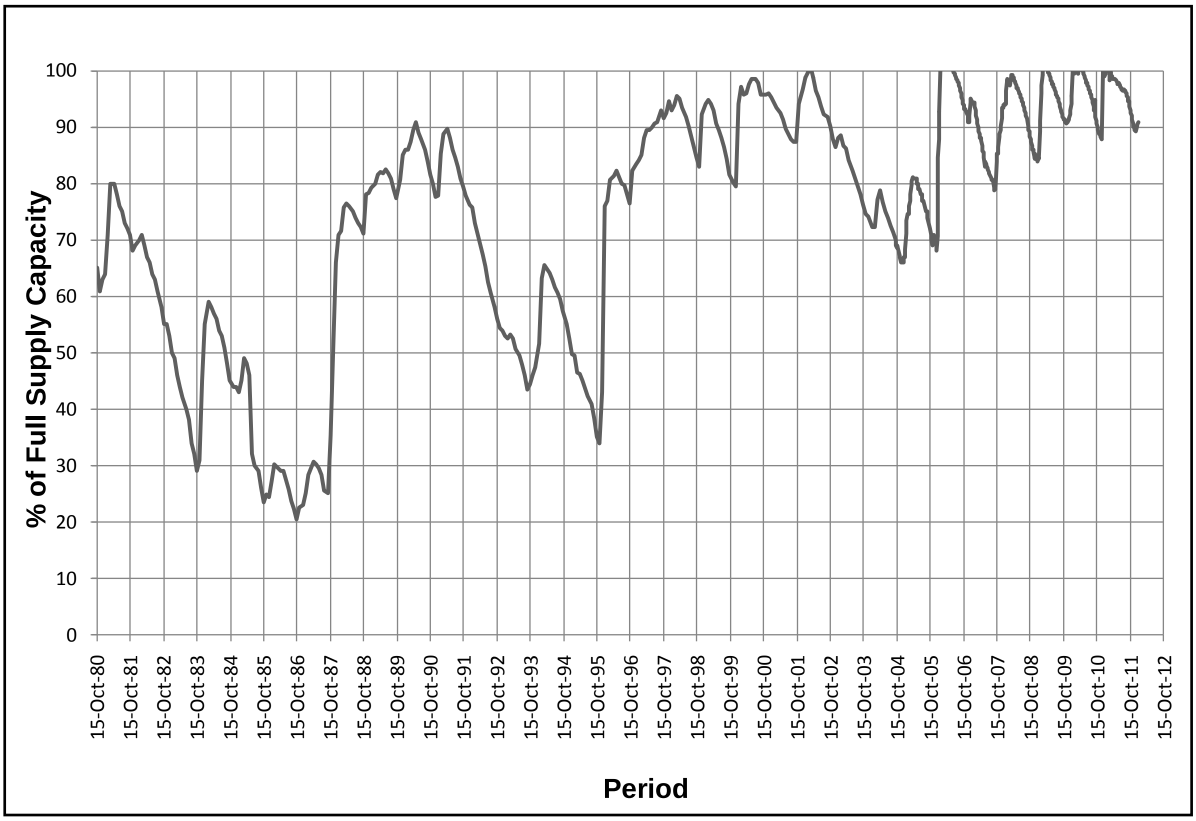

Figure 4-10: Percentage water in storage in the Upper Vaal Management Area (Vaal Dam and above) since 1980

The observed record of river releases from the Grootdraai Dam (component G22 at hydrological station C1R002) is shown in Figure 4-11. The releases included compensation releases for consumers along the river up to Vaal Dam, releases to augment Vaal Dam, and spills that occurred when the dam was full. The records were analysed and it was found, as can also be graphically observed from the release record and from the periods that the dam was not full (see Figure 4-7), that little water was released to augment the Vaal Dam, i.e. the transfers were largely intended to augment the yield of Grootdraai Dam itself.

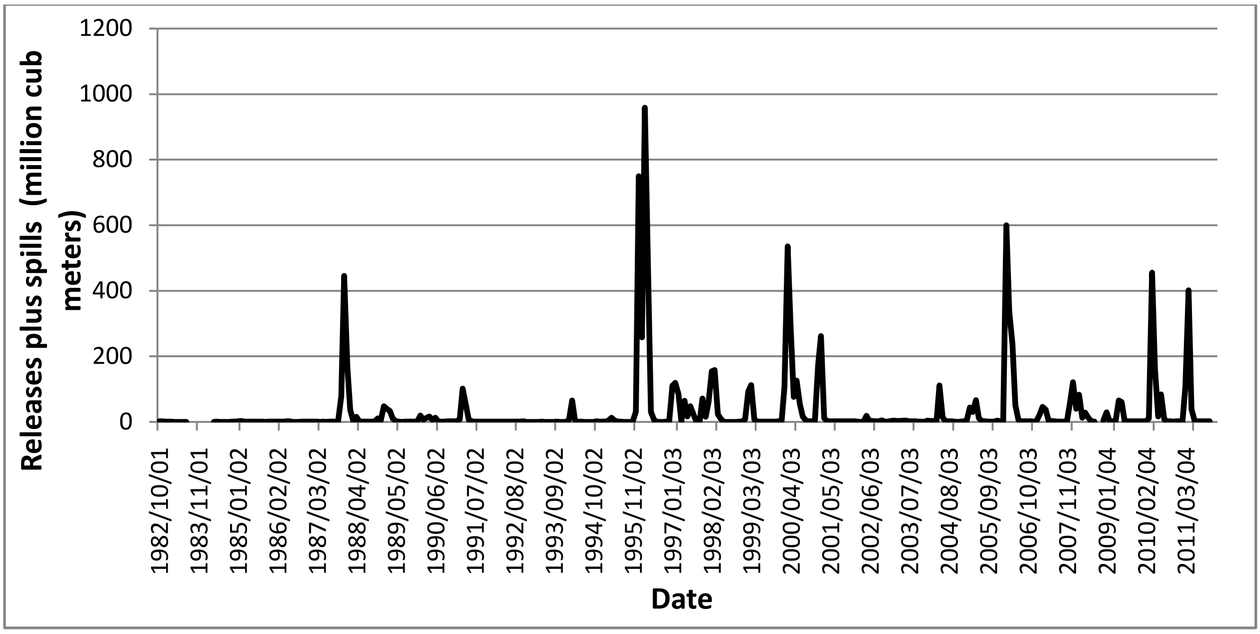

Figure 4-11: River releases at Grootdraai Dam

The very variable characteristic of the actual water transfers, depicted in Figure 4-6, was also considered. While the demand pattern from Grootdraai Dam did exhibit some variability around its trend, this could be explained by the fact that other water resources are also utilised by some of the power stations, as noted in par. 4.2.7. The variability of the demand was, in any case, of a far lesser extent than that exhibited by the transfer record.

4.2.11 Conclusions regarding transfers from the Usutu-Vaal River GWS

This part of the investigation examined possible factors that could explain the difference between the envisaged and the actual inter-basin transfers of the Usutu-Vaal River GWS (Second Phase). It was found that:

(a) The transfers from the Usutu-Vaal River GWS (Heyshope Dam) should be viewed in combination with the (subsequently built) Slang River GWS transfers in order to obtain a complete perspective of required water transfers

(b) The growth in water requirements was generally lower (after initial rapid growth) than had been envisaged in 1981

(c) The estimated system yield was revised a number of times as new information and more sophisticated analytical methods became available, confirming that the two IBT schemes were required, i.e. met their objectives

(d) The initially found overestimation of the volume of water transferred from the Usutu-Vaal River GWS (Second Phase) reduced with further examination of the total (combined) transfers. It was found that, applying the methodology of the planners in 1981, there would still have been an overestimation, but this had reduced to 45% (from the initial 400% observed in par. 4.2.2).

While these findings demonstrated that the methodology used in 1981 can lead to a significant over-estimation in volumes of water to be transferred by an IBT, the cause of the underestimation and the variability the transfers exhibited, requires further examination. This is undertaken in the next section (paragraph 4.3).

4.3 Examining actual operational decision-making of an integrated water resource system

In this section the actual decision-making during the operation of the Integrated Vaal River System (IVRS) is examined with specific reference to IBT water transfers to Grootdraai Dam.

4.3.1 Introduction

The previous section (paragraph 4.2) found that the methodology used by the water resource planners of the Usutu-Vaal River GWS (Second Phase) resulted in an overestimation of some 43% of the quantity of water to be transferred. It also confirmed that the characteristic of the transfers of both the Usutu-Vaal River GWS (Second Phase) as well as the Slang River GWS (Zaaihoek Dam) was typified by variability from year to year. The purpose of this section is to establish the cause of this variability and to demonstrate the need for an integrated, comprehensive analysis at the planning stage to predict water transfers.

Again the water transfers from Heyshope and Zaaihoek Dams are considered.

4.3.2 Background

The complexity of the Vaal River System, with its interlinked water resources and numerous demand centres, was described in Chapter 1 and schematically illustrated in Figure 1-4. Annually, at the end of the rainy season, the DWA undertakes an analysis in order to set the operational regime for the following year. This, so-called, Annual Operating Analysis (AOA) of the IVRS takes into account the state of the system (i.e. storage of each dam) as at 1 May of each year. The analysis is conducted soon afterwards (Swart, 2012a).

The AOA entails running DWA's Water Resources Planning Model (WRPM) (described in paragraph 2.2.3) to simulate the behaviour of the IVRS, usually, for 1000 stochastic time-series of flows of 20 year duration. This is repeated for various scenarios to test the impact of variations in operational rules, different growth projections, and possible changes to the configuration of the system. If the hydrology of the system, or parts of the system, have been updated, the time-series of the stochastic flow is adjusted accordingly.

The AOA points at risks of possible water shortages, usually three, but sometimes more, years into the future. The recommendations for the operation of the system for the cycle, ending in April of the following year, takes such risks into account, but also considers aspects such as the costs of operation, e.g. pumping of water.

On a quarterly basis during the year in question, the operation of the system is reassessed, and the operating rules updated, taking into account possible changes, or unexpected circumstances, that may reveal themselves during the period, e.g. good rains or unforeseen failures of equipment (Swart, 2012a).

4.3.3 Reporting

An AOA report is produced annually, covering the following topics:

a) Starting conditions of the IVRS
b) Water requirement projections: updates and scenarios
c) Projected changes to system configuration and characteristics for the period of analysis, e.g. implementation of new infrastructure, or rehabilitation of infrastructure
d) Results of simulations
e) Recommended operation for the year (1 May to 30 April) ahead.

The AOA reports covering a period of 22 years, starting 1990/91 and ending 2011/12 (except for the years 1997/98 and 1999/2000, due to unobtainable reports), were studied to see how the IBTs from Heyshope Dam and Zaaihoek Dam (see Chapter 3 for description of these IBT projects) were operated in the light of the conditions in the rest of the IVRS over that period, and in particular that of the Vaal River Eastern Sub-System (VRESS) to which these IBTs are linked.

4.3.4 The Vaal River Eastern Sub-system (VRESS)

The VRESS is a very important sub-system of the IVRS; it supplies water to the Eskom power stations on the Eastern Highveld where 80% of South Africa’s power generating capacity is located, the strategically important SASOL 2 and 3 fuel-from-coal facilities and other, mainly coal-based, industries as well as a number of smaller users and municipalities. The schematic depiction of the VRESS in Figure 4-12 (Swart, 2012a) shows the linkages with the Heyshope Dam sub-system (the upper Assegai River), the Zaaihoek Dam on the Slang River, The Usutu sub-system with its three dams, Westoe, Jericho and Morgenstond, the Komati sub-system with the Nooitgedacht and Vygeboom Dams, the VRESAP linkage with Vaal Dam and the Grootdraai subsystem, with Grootdraai Dam that plays a central role in the operation of the VRESS.

This investigation focuses on the water transfers from the Heyshope Dam and the Zaaihoek Dam, to establish the main factors that influenced decisions on the water transfers. These factors are expected to be largely contained within the VRESS.

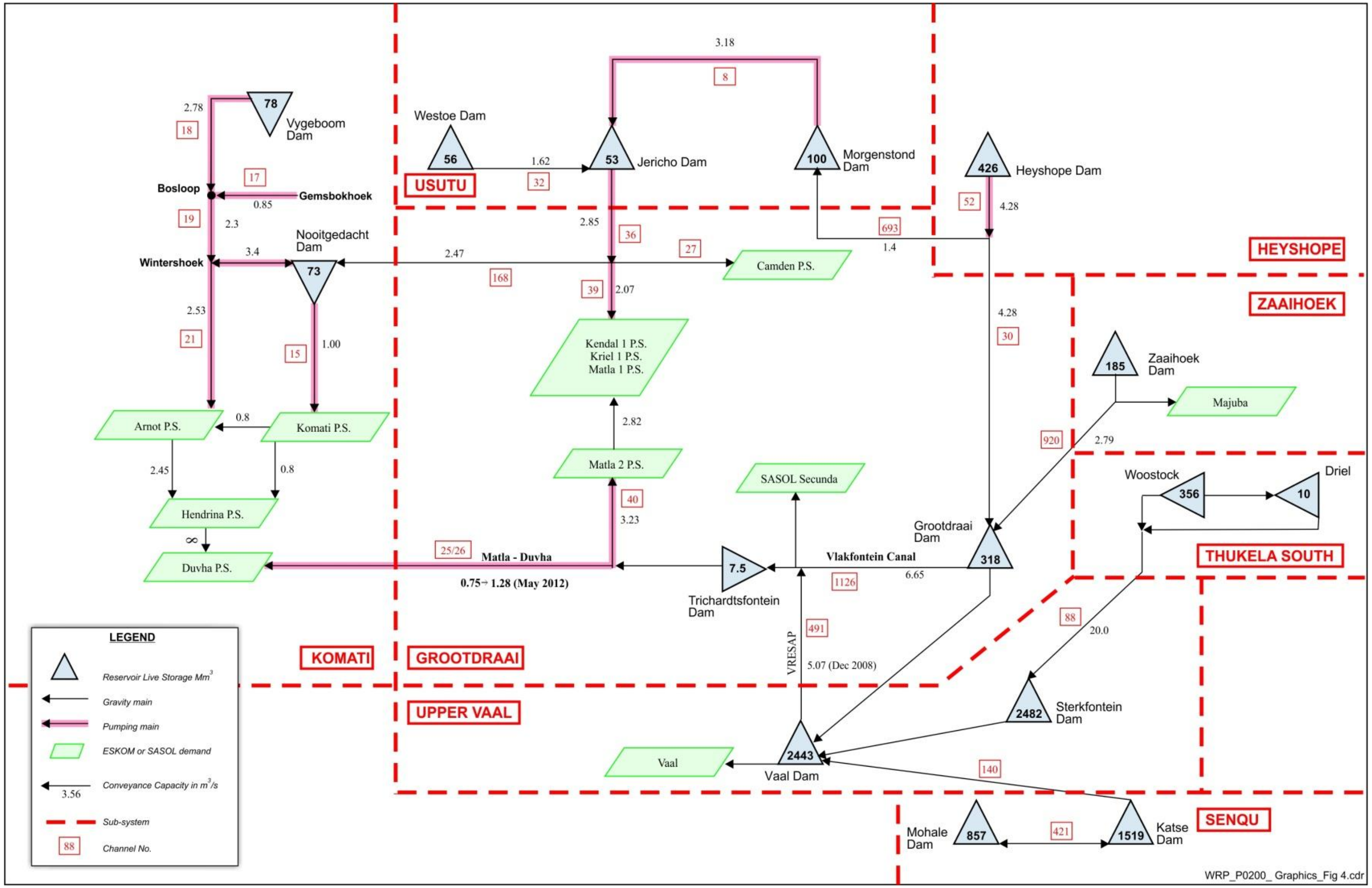

Figure 4-12: Schematic of the Vaal River Eastern Subsystem (VRESS)

4.3.5 A 22 year view of operational decision-making

The data relevant to the reconstruction of the behaviour of the inter-basin transfers from the Heyshope and Zaaihoek Dams, sourced from the AOA reports of the Department of Water Affairs between 1990/91 to 2011/12 (except for the years 1997/98 and 2000/2001), are summarised in ANNEXURE 4-B. A time-line perspective could be obtained of the four variables that influenced the recommendations and therefore the operation of these transfers; the state of the system at decision date, the changes in system configuration and capacity, the projections in demand on the system for the short and medium term and the levels of assurance of water supply.

4.3.5.1 State of the system

The state of the system at the decision date is influenced by the inflows the dams received in the preceding period and the abstractions that were made. Of these the inflows are by far the dominant factor; abstractions are more stable and predictable as is shown in paragraph 4.3.5.2 below.

During the 22 year period the system storage generally remained at fairly high levels except for a period between 1992/93 and 1995/96 when a drought occurred. This drought was of such a severity that restrictions had to be imposed on all water users on 1 April 1995. Irrigation water users were restricted by 40%, municipal users by 20%, mines and SASOL by 10% and Eskom power stations by 5%. After exceptionally good rains in November 1995 the drought was broken. Restrictions were lifted in January 1996.

For the four years of the drought large quantities of water were transferred from the Heyshope and the Zaaihoek dams. Problems with the pumps at the Geelhoutboom pumping station at Heyshope prevented continuous transfer at maximum capacity during these years. The policy at first was to keep all the water transferred in Grootdraai Dam, i.e. not to support the rest of the system. When Grootdraai Dam filled completely (largely as a result of the transfers) it was decided to continue pumping as there were delays in bringing the Lesotho Highlands Water Project (LHWP) on stream, keeping Grootdraai Dam full and the spills to augment Vaal Dam. All transfers were stopped in December 1995 due to the system having recovered completely from the drought.

After the drought years of 1992/93 to 1994/95 the operating rule for transfers to Grootdraai Dam followed a fairly consistent pattern; the two transfer projects were treated in tandem and similar recommendations made for transfers from the Heyshope Dam and the Zaaihoek Dam for the year that lay ahead. These recommendations were based on the likelihood that water shortages may develop in the short to medium term and typically read as follows:

Inter-basin transfers from Zaaihoek Dam and Heyshope Dam to Grootdraai Dam to be made when Grootdraai Dam is below X% of its net full supply storage.

For eleven out of the sixteen years since the drought, X was set at 75%. During these years the starting storages of Grootdraai Dam averaged 96.1%. For four of the years a 90% rule was adopted. The average starting storage in these cases was 95.2%, which is not significantly different to the average for the 75% rule. It is noticed that three of these years occurred in the five years before the VRESAP pipeline started at the end of 2008 to augment the system from the Vaal Dam. This is consistent with the behaviour that can be expected of a system that is moving closer to its maximum safe yield capacity, with a growing demand and just prior to the system being augmented.

Only in a few isolated instances did the state of storage in the rest of the system, other than that of Grootdraai Dam, influence the operating rule adopted for the transfers from Zaaihoek Dam and Heyshope Dam. During the drought years of 1992/93 to 1994/95 the rule was set that transfers should cease when the Grootdraai Dam reached 95%, but, due to the very low state of the rest of the system in January 1994, it was decided to continue with the pumping despite the fact that Grootdraai Dam was full. An additional rule was added that pumping should continue until Sterkfontein Dam, which was being supported from the Thukela River by means of the Drakensberg scheme, was 99% full. This effectively meant that the Zaaihoek and Heyshope transfers supported the Vaal Dam for the period January 1994 to December 1996. For the rest of the 22 year record under examination, the state of storage in Grootdraai Dam determined the transfer regime from Zaaihoek and Heyshope.

4.3.5.2 Demand

In each AOA, the predicted growth in water demand on the system was considered. In the initial years the growth rate predictions were based on the (so-called) TR 134 report (DWA, 1988), adjusted for actual water use in the prior year. As updated forecasts from the large users, Rand Water, Eskom and Sasol, mainly, were received, the projections were adjusted.

In the earlier AOA reports only the gross demands, i.e. before account is given for return flows, were mentioned. In the Vaal River System return flows, typically returns from municipal sewage treatment works and irrigation drainage back to the rivers, play a significant role as these returns are being used again down-stream. The later reports gave both the gross and net demand information. It is therefore possible to trace the changes in prediction of the short and medium term demands and to make an assessment of the variability of such predictions over the period of study.

ANNEXURE 4-D summarises the short and medium term projections for each AOA year. It is noticeable that the projections from annual assessment to annual assessment for a particular year in the future, e.g. 2010, usually vary within a few percent. At times, though, abrupt changes are noticeable. These required further examination.

The drought of 1992/93 to 1994/95, and the resultant restrictions during 1995, had a marked effect on consumption. The base demand for the projections had to be adjusted and projections revised (downwards) in the AOA of 1996/97. The 2004/05 AOA also significantly lowered projections in accordance with the National Water Resource Strategy (NWRS). For the 2006/07 AOA the supply area of the IVRS was increased to include the Lower Vaal, and the towns Witbank and Middelburg, consequently increasing the water requirement projections. Due to electricity shortages Eskom started a programme to refurbish and reinstate certain older decommissioned power stations, which increased its water requirements. This increase was included in the 2007/08 AOA. The 2010/11 AOA reduced its projections for 2015 as it took note of measures to curb unlawful water use in the Vaal River System as well as concerted efforts being undertaken to reduce demand through the implementation of various water demand management measures.

On balance, taking into account the explanation for the obvious perturbations that occurred, the projections remained markedly stable from AOA to AOA, i.e. from year to year. While these projections are important inputs into the operational analyses, the stability of these projections means that the changes observed in the actual annual water transfers from Heyshope and Zaaihoek to Grootdraai Dam are not explained to any significant degree by water demand projections adopted in the AOAs.

4.3.5.3 Configuration

Every AOA considered changes to the entire IVRS that could influence the operational regime for the year ahead. Numerous smaller changes were included over the 22 years but the more significant ones were the addition of a pipeline link from the Heyshope Dam subsystem to the Usutu sub-system, whereby the Morgenstond Dam on the Ngwempisi River could be supported from Heyshope Dam at a maximum rate of 1.4 m^3/s as well. This facility was seldom required during the 22 years, as can be seen from ANNEXURE 4-B.

A major augmentation to the system was made with the additions of the LHWP; water delivery from Katse Dam started in January 1997 and this was followed by Mohale Dam in March 2004. The LHWP supplied water into Vaal Dam which meant that Grootdraai Dam and its sub-system did not directly benefit from it. This changed when the large VRESAP linked the Vaal Dam (see paragraph 4.2.6 for description) with the Grootdraai subsystem in December 2008.

After the addition of the LHWP, the Heyshope and Zaaihoek transfers were not required to augment any other part of the IVRS than the Grootdraai sub-system. With the VRESAP scheme now in place these transfers are logically confined to the support of the Grootdraai subsystem only.

4.3.5.4 Assurance Levels

The assurance of water supply to the different user sectors forms an input for the annual operational analyses. Small adjustments of this factor occurred during the 22 year period of observation, but these were confined to the domestic and irrigation sectors. The strategic industry sector was accorded a 99.5% level of assurance of its entire requirement throughout. This latter requirement being the bulk of the supply from Grootdraai Dam, it can be concluded that there had been no effect on the operation of that sub-system and, by implication, the transfers from Heyshope and Zaaihoek dams.

4.3.6 Discussion and conclusion regarding operational decision-making to explain the difference between projected and actual water transfers

The observation of operational analyses of the IVRS over a 22 year period, with the specific focus on the behaviour of the Heyshope and Zaaihoek water transfers into the Grootdraai subsystem, revealed that:

(a) While the AOAs considered the whole of the IVRS, in all its complexity, the resulting operating rules for the IBTs were not complex at all and were reduced to taking cognisance of the state of storage in a particular sub-system for the year ahead

(b) For most of the period studied, the quantities of water annually transferred from Heyshope and Zaaihoek were linked to the state of storage in the Grootdraai Dam

(c) Demands generally only varied gradually from analysis period to analysis period and did not lead to the variability exhibited by the transfers

(d) Changes in configuration of the IVRS over the period were few and could not, even indirectly, explain the variability exhibited by the transfers

(e) The levels of assurance of supply used in the operational analyses differed only marginally over the period and had no significant effect on the two water transfers

(f) Equipment failure during the worst drought of the period caused an under-performance of the Heyshope IBT.

It follows that, as the Heyshope and Zaaihoek transfers are primarily determined by the state of storage in the Grootdraai Dam, and this latter storage is dependent on the inflow into the dam, i.e. the run-off arising in its catchment (excluding the water transferred in, as this is not an independent variable), the Heyshope and Zaaihoek transfers by extension are dependent on the run-offs that occur in the catchment of the Grootdraai Dam, i.e. the receiving catchment. By analogy, this dependence would be an inherent characteristic of any IBT that transfers water into a receiving system that has its own water resources.

Returning to the planning of a new IBT project; recognising the findings above it follows that a determination of quantities of water required to be transferred would involve undertaking an integrated systems analysis. Such an analysis will have to consider the source system in conjunction with the system on the receiving side in order to obtain a realistic perspective of the transfers that are likely to take place after an IBT has been constructed.

In cases where the receiving system may already be complex, as was seen in this case study, it may be considered to delimit the receiving system to include only the major resources and demands that are dependent on the transfers. In the case study above, such delimitation of including only the Heyshope, Zaaihoek and Grootdraai Dam subsystems would significantly reduce complexity, but give the realism sought for accurate planning purposes.

4.4 Review of water transfer data of the Tugela-Vaal Government Water Project

This section examines the actual water transfers of the Tugela-Vaal GWP.

4.4.1 Background

The locality of the Tugela-Vaal GWP is presented in Figure 4-13. The system is operated by the DWA except for the portion through the Drakensberg hydropower pump-storage scheme, between the Kilburn and Driekloof Dams, which is operated by Eskom. The water that DWA pumps into Kilburn Dam equates the quantities destined for storage in Sterkfontein Dam plus the losses (mainly evaporation) in Sterkfontein Dam. Water is released from Sterkfontein Dam in the Wilge River whenever required by the Vaal River System.

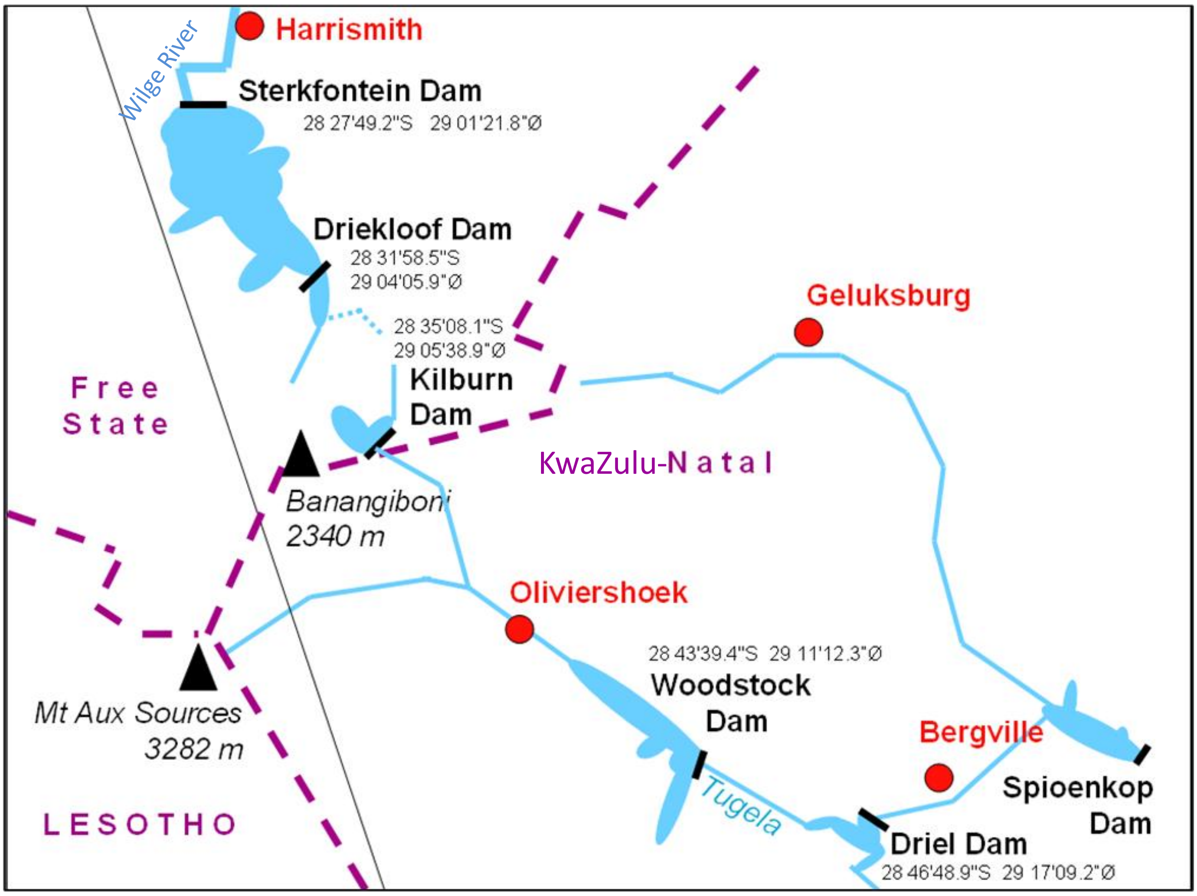

Figure 4-13: Locality of the Tugela-Vaal GWP (adapted from Wikimedia, n.d.)

The Tugela-Vaal GWP started as a scheme that directly pumped water over the escarpment from the upper Thukela (previously Tugela) River to the Wilge River (as tributary of the Vaal River) in the early 1970s. This was replaced in the early 1980s with a joint scheme with Eskom that utilised the Drakensberg hydroelectric pump storage facility to pump water against a total static head of some 500 meters over the escarpment. Initially this facility was intended to transfer 11 m^3/s, or 346.9 million m^3 /year (DWA, 1980:9), in order to increase the net Vaal River System yield by 800 million m^3 /year. However, due to a severe drought in the early 1980s, the design was changed to increase pumping capacity to 20 m^3/s “to increase the assurance of water supply” (DEA, 1984:1). The annual volume to be transferred and the estimated increase in net system yield remained the same as in the earlier WP and the annual projected “water sales”, i.e. the quantity of water pumped into Sterkfontein Dam, was indicated as 346.9 million m^3 for every year after 1982/3 for the duration of the economic life of the project (ending in 2028/29).

4.4.2 Water transfers from the Thukela River to the Vaal Basin

While it was not possible to obtain a full record of actual water transfers from the Thukela[5] River to the Vaal Basin, i.e. the records of water physically pumped into Kilburn Dam – not from the DWA nor from Eskom – the records of water released from the Sterkfontein Dam into the Wilge River over the period 1981 to 2009 were obtained from DWA and can be used as a proxy for the quantity of water pumped over the divide from the Thukela Basin (the natural runoff into the Sterkfontein Dam is less than the net evaporation from the dam). The annual quantities released are shown in Figure 4-14.

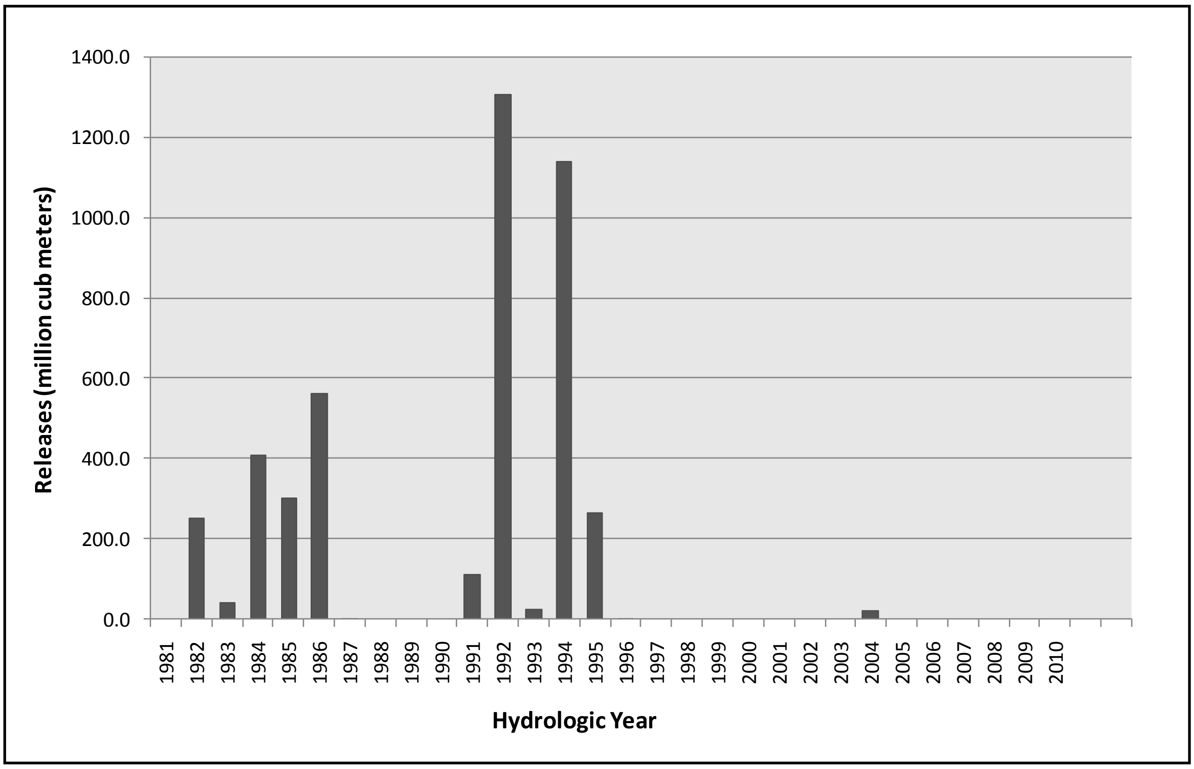

Figure 4-14: Historic releases from Sterkfontein Dam

Although transfer data were lacking, it can be concluded from the releases from Sterkfontein Dam that the transfers were likely not to be continuous, but variable over the period. (This was confirmed by the AOA report analyses – see paragraph 4.4.4). The quantity of water required from the transfer scheme over the 28 year period averaged 158.5 million m^3/year, or only 46% of that which had been estimated to be transferred (on average) in the White Papers of 1980 and 1984.

As further corroboration of this observation the actual levels of the main storage dam on the Thukela side, the Woodstock Dam, are compared against that predicted during the planning stage, as discussed in paragraph 4.4.3.

[5] Most recent spelling.

4.4.3 Woodstock Dam level: observed against predicted

In White Paper J-84, dealing with the extension of the second phase of the Tugela-Vaal GWP the Department of Environment Affairs[6] reported on investigations undertaken to determine the effect the increased transfers would have on the water levels of the Woodstock Dam. It was found that there would be a significant drop in average dam levels leading to a concern that the denuded areas, when the dam would be relatively empty, would spoil an otherwise highly scenic area (DEA, 1984:10). This was due to fact that the envisaged increased transfers from the dam were expected to exceed the "dependable yield" of the dam (1984:9).

The envisaged dam level characteristics of White Paper (WP) J-84 were compared against the DWA records of Woodstock Dam, gauge V1R003, from March 1985 to June 2009. (Although recordings started in March 1983, the dam filled the first time in March 1985 – the records for this initial "warming-up" period were therefore not included.) The results are shown in Table 4-3.

Table 4-3: Woodstock Dam (V1R003): Actual against predicted dam levels

Woodstock Dam % of full cap	% of time estimated in WP J-84	% of time in reality over 24 years
0-1	12	0
1-20	14	4
20-40	17	5
40-60	16	9
60-80	15	16
80-100	13	48
100	13	18

Over 24 years the Woodstock Dam was generally at a higher level than was predicted. This corroborates the observation reported in paragraph 4.4.2 above that less water had been transferred over the period than envisaged at the planning stage.

Greater insight regarding the reasons for the reduced transfers can be inferred by inspecting the annual operating reports that determined the operational decision-making.

4.4.4 Thukela-Vaal operational decision-making

As with the investigation into the transfers into the VRESS (see paragraph 4.3.5), the available AOA reports for the IVRS between the years 1990/91 and 2011/12 were examined

[6] In the 1980s the Department of Water Affairs was absorbed for a short period into a new Department of Environment Affairs.

with respect to the decision-making to transfer water from the Thukela to the Vaal. The results are summarised in ANNEXURE 4-B.

It was found that the state of the system, especially that of the large storages, i.e. Vaal Dam and Sterkfontein Dam, and later Katse Dam in Lesotho, determined the decision whether or not to pump from the Thukela River to Sterkfontein Dam. Out of the 20 AOA reports only seven, for the years 1990/91 to 1996/97, recommended that transfers be made. For the rest of the period no transfers were indicated.

4.4.5 Discussion

The observation that the water levels in Woodstock Dam were higher than originally envisaged supported the observation that less water than was envisaged in the original White Papers had been transferred from the Thukela River to the Vaal Basin. It also indicates that there is a need to consider more carefully not only the quantities likely to be transferred by an IBT project, but also that the regime in the source catchment below such an IBT project requires more careful consideration. The Incremental Approach may lead to inaccurate predictions of what is likely to happen downstream and this may affect decisions related to environmental requirements, as an example.

The AOA reports showed that transfers from the Thukela River were required when the Vaal River System was stressed. Releases from Sterkfontein Dam earlier required the pumping in the early 1990s to replenish Sterkfontein Dam and this was followed by a serious drought in the mid 1990s when restrictions were required as noted in ANNEXURE 4-B. The transfers were required for only seven years. Whereas White Paper J-84 envisaged pumping every year, this was not required for the rest of the period due to the generally favourable state of storage in the system the rest of the time. In addition capacity expansion, such as after the completion of the Katse Dam in Lesotho, provided added security for the initial years when incremental demands were lower than the added yield assurance. The operators of the IVRS could select those resources with lowest variable costs in order to minimise total annual operating expenditure.

Lastly, the investigation revealed a lack of monitoring of water transfers on the part of the DWA. A simple question, ”How much water had been transferred from the upper Thukela to the upper Vaal since the construction of the Tugela-Vaal Project?”, could not be answered because of a lack of record-keeping. This is problematic, not only as it is incumbent on the DWA to maintain a coherent hydrological information database, but also because the DWA is charged by Eskom for water transferred to Sterkfontein Dam via Driekloof Dam[7].

4.5 Conclusions regarding mismatches between projected and actual water transfers

This chapter examined the reasons for the apparent differences in water transfer projections during the original planning stage of an IBT scheme and the transfers that occurred in practice subsequently, after implementation of the IBT.

Two case studies of IBT schemes that were built in the 1980s were examined. The first one dealt with the Usutu-Vaal River GWS (Heyshope Dam) and the Slang River GWS (Zaaihoek Dam) that, jointly, augment the Grootdraai Dam of the Vaal River Eastern Sub-system. The second, the Tugela-Vaal GWP, transferred water from the Thukela Basin into the Vaal River System.

Both case studies confirmed that the volumes of water transferred were significantly less than the planners originally envisaged. In the first case study, account was given of possible specific reasons, such as a change in growth rate of demand and physical impediments to transfer (e.g. pumps that failed), but it was demonstrated that a large discrepancy between what had been forecasted and what actually transpired still remained. The cause of the discrepancy lay in the method of annually deciding on the operation of the IVRS as a whole.

The AOA takes as its point of departure the state of system storage at the beginning of its cycle. From the analysis of the reports over a 22 year period it was evident that the state of storage of Grootdraai Dam largely determined the operation of the Usutu-Vaal River and Slang River schemes, and similarly the state of storage of the Vaal Dam, the releases from Sterkfontein Dam and the transfers from the Thukela River to Sterkfontein Dam. From this observation it can be concluded that, generally, IBT operations would have a strong dependency on the state of storage in the receiving catchment, particularly too when the variable costs of the operations of the IBTs are significantly higher than those of the resources in the receiving basin – which often is the case. It must also be concluded that the planning of a new IBT project, in assessing likely water transfers, must of necessity take cognisance of the fact that these transfers will be strongly linked to the state of the system – which includes the receiving part thereof. The Incremental Approach does not include such recognition.

[7] Eskom calculates the cost from the difference between the energy consumed for pumping water to the upper Driekloof Dam and the energy generated when the water is released back to Kilburn Dam - suitably factor-adjusted (Schirge, 2011). DWA does not seem to check these charges against records of augmenting the lower Kilburn Dam.

In both cases the original project appraisals did not consider uncertainty of future water transfers. Uncertainty is to be expected due to natural hydrological stochasticity in the rest of the supply system and its effect on the operational decision-making. A comprehensive systems simulation is required at project appraisal stage to simulate operations, taking into account relative variable operating costs (e.g. pumping costs) associated with water transfers.

The findings of this chapter conclusively support the first sub-hypothesis: *The Incremental Approach of IBT project appraisal does not adequately consider receiving catchment conditions and a comprehensive systems simulation is required at project appraisal stage if variable costs (e.g. pumping costs) are associated with water transfers*. The next chapter investigates whether the Incremental Approach is still commonly followed when appraising IBT projects.

5 Confirmation of Incremental Approach currently in general use

In this chapter six case studies are examined to ascertain whether the Incremental Approach of IBT project appraisal is still generally being followed.

5.1 Introduction

In Chapter 4 the shortcomings of the Incremental Approach in the planning of IBT schemes were demonstrated, in particular that they do not take cognisance of the likely operational decision-making which will be directly related to the state of storage in the receiving catchment where variable operational costs have a significant impact.

The current practice with respect to the appraisal of proposed IBT schemes is investigated in this chapter – whether it differs significantly from the Incremental Approach used in the historic case studies examined in Chapter 4. Again the case study research methodology will be used.

5.2 Selection of case studies

As shown in Table 5-1, four case studies from the RSA were selected on the basis of these being recent investigations conducted by four different sets of service providers, recognised locally and internationally as of high standing in the field of water resource engineering and management.

Table 5-1: RSA case studies

Number	Name of Project	Date of completion	Service provider	Client
Case Study 1	Mooi-Mgeni Transfer Scheme - Phase 2: Selection of water transfer system	March 2009	BKS (Pty) Ltd	TCTA
Case study 2	Mkomazi-Mgeni Transfer Scheme Pre-feasibility Study	May 1999	Ninham Shand Consulting Engineers	DWAF and Umgeni Water
Case Study 3	Mokolo and Crocodile (West) Water Augmentation Project (MCWAP)	September 2010	Africon in association with Kwezi V3 Engineers, Vela VKE, and WRP Consulting Engineers	DWA
Case Study 4	Vaal River WRDP: Comparative Study between LHWP II and Thukela Water Project	October 2010	ACER (Africa), BKS, DMM Development Consultants, Golder Associates Africa and WRP Consulting Engineers	DWA

Two further case studies of origin beyond the borders of the RSA are investigated to ascertain whether, internationally, the appraisal approaches used there differed materially from the Incremental Approach used in the RSA. The two studies are listed in Table 5-2.

Table 5-2: International case studies

Number	Name of the project	Date of completion	Lead firm/investigating agency	Client
International Case Study 1	Wanjiazhai Water Transfer Project (WWTP)	Appraisal 1997 Implementation completion and results 2007	World Bank	Government of the People's Republic China
International Case Study 2	Water augmentation to South East Queensland, Australia	Various reports – from 2006 to 2010	Various Australian consultancies	Government of Queensland. Queensland Water Commission

5.3 Criteria of assessment

The extent to which the appraisal methodology applied in each case study coincides with the Incremental Approach is assessed by applying the following criteria:

a) Was the assumption made that all incremental demand, beyond the yield capability of the existing system, was to be supplied from the IBT and subsequent water resource capacity expansion?
b) Has a fully integrated system analysis of both source and receiving systems, with the inclusion of the proposed IBT project, been undertaken?
c) If so, did the full system analysis include the simulation of annual operational decision-making?
d) If so, were the transfers due to the IBT identified and the time-series used in further analysis?

If the answer to the main criterion a) is in the affirmative, the Incremental Approach has been followed. If not, the criteria b) to d) are to be checked to conclusively establish that a different approach had been followed.

5.4 Structure of case studies

For conformity each case study has been structured as follows:

a) A description of the background of each case, its locality, motivation for the need for an intervention and the potential alternatives
b) A summary of the investigation undertaken: available yields and the water requirements, future water transfers, the elements of options and their capital costs, recurrent costs, economic analysis and study recommendations
c) An evaluation of the case to establish the extent to which it followed the Incremental Approach.

In certain cases additional information is provided as annexures to the dissertation.

5.5 RSA Case Study 1: Mooi-Mgeni Transfer Scheme – Phase 2

This case study examines the appraisal process applied during the investigation into the Mooi-Mgeni IBT.

5.5.1 Background

The purpose of the Mooi-Mgeni Transfer Scheme Phase 2 GWS (MMTS-2) of the DWA is to augment the resources of the Umgeni Water supply area. The scheme entails a dam at the site Spring Grove on the Mooi River and a pipeline conveyance structure to transfer water to the Mpofana River, to the upper reaches of the Mgeni River catchment, upstream of Midmar Dam. In 2007 the then Minister of Water Affairs and Forestry approved the project and appointed the Trans Caledon Tunnel Authority (TCTA) to implement the scheme. Figure 5-1 depicts schematically the layout of the existing dams and conveyance structures as well as those to be constructed as part of the MMTS-2. Also shown are the demand centres of the Mgeni supply area (DWA, 2009:4).

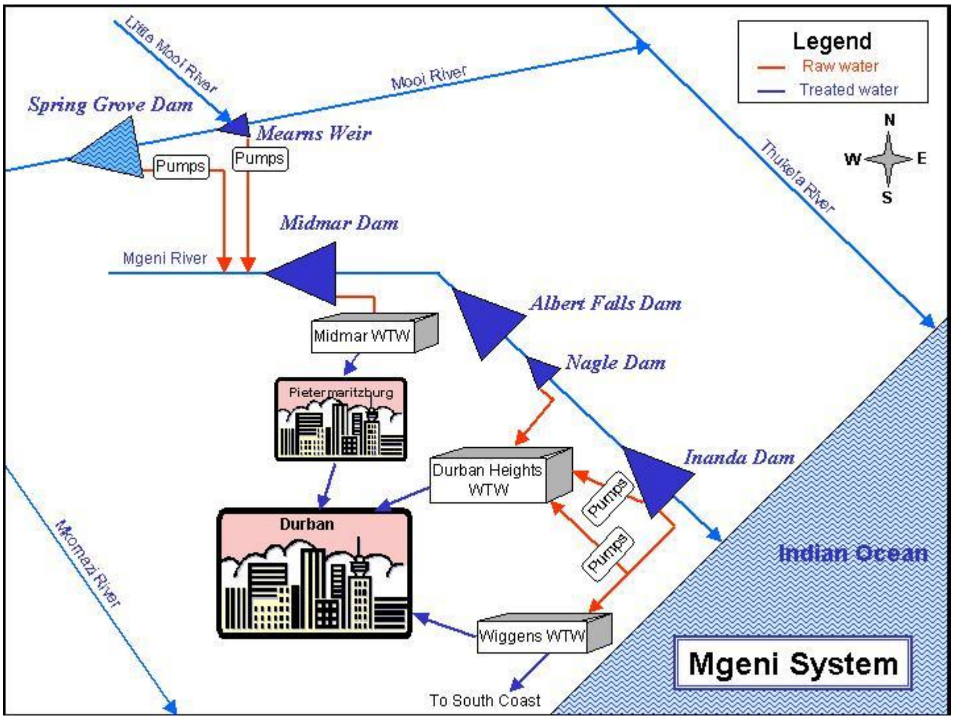

Figure 5-1: Schematic of the Umgeni water supply area and the MMTS-2

The first phase of the Mooi-Mgeni Transfer Scheme (MMTS-1) was built already in the mid 1980s as an emergency scheme due to a severe drought that hit the area (DWA, 1983). It consisted of a weir in the Mooi River on the farm Mearns, a pumping station with a capacity to transfer of 3.2 m^3/s against a total head of approximately 100m, and a 21.6 km pipeline to the Mpofana River. It was estimated that the scheme was able to contribute 27.3 million m^3 per year during a drought of the proportions experienced at the time (DWA, 1983:3). The Mearns Weir was raised in 2003 to create about one week's storage. With the substantial further additional storage from the Spring Grove Dam it was estimated that the 1:100 yield of the Umgeni System would increase by 60 million m^3/a to 394 million m^3/a (DWA, 2009:6).

In January 2009 the TCTA, a statutory body assigned for the construction of the Spring Grove Dam and transfer works, appointed the firm BKS (Pty) Ltd to review earlier investigations and undertake a comparative study of two options earlier identified to transfer water from the Spring Grove Dam in KwaZulu-Natal to the Midmar Dam catchment. These options were (a) conveying water by gravity through a tunnel or (b) transferring water by means of a pumping station and pipeline system. A report on the investigation was issued in March 2009 (TCTA, 2009).

5.5.2 Summary of investigation

This section summarises the investigation and its findings.

5.5.2.1 Quantities required to be transferred

The investigation noted that the schemes to follow the MMTS-2 were likely to be two dams on the Mkomazi River; the Smithfield Dam and the Impendle Dam (see also RSA case study 2 and locality in Figure 5-3). As the conveyance structure to link these dams to the Mgeni supply area could result in a considerably lower operating cost than pumping from the Mooi River, two cases of the latter pumping option were investigated; one where water would only be pumped from the Mooi River to meet shortfalls not met by the two Mkomazi River dams (the intermittent transfer case) and one where water would be pumped continuously (the continuous transfer case) as illustrated in Figure 5-2.

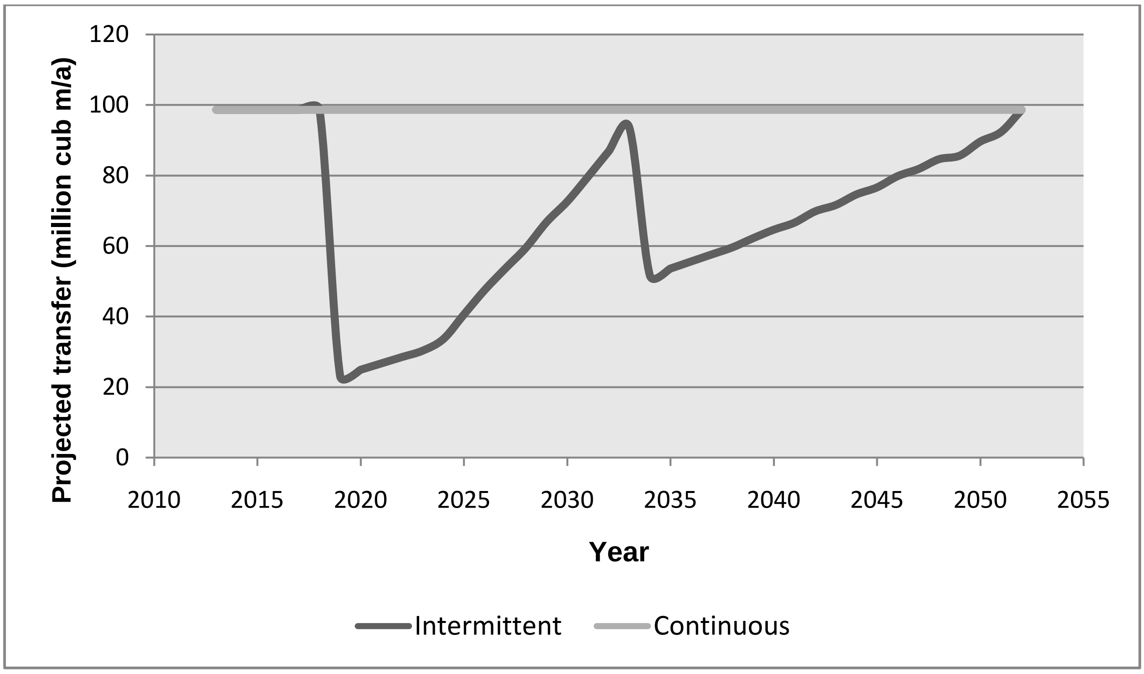

Figure 5-2: MMTS-2: Transfers from Spring Grove Dam

It was assumed water transfers would start in 2013 and that the full annual yield of the Spring Grove Dam of 98.6 million m^3, being the total water available for transfer at 1:100 year level of assurance (TCTA, 2009:3), would be required to be transferred from the start due to the fact that the total system requirements would exceed the supply already at that date.

5.5.2.2 Proposed works and capital cost of pumping option

The conceptual design of the pumping option entailed a pumping station below Spring Grove Dam with a maximum capacity of 4.5 m^3/s, three pumps operating against a maximum head of 97,8 meters, a 6.74 km rising main of 1400 mm diameter, a break-pressure tank and a 7.68 km gravity pipeline of 700 mm diameter. (The existing MMTS-1 gravity pipeline will remain in use.) The existing outlet structure at the Mpofana River was to be upgraded as well.

The total construction cost was estimated at R258 million at January 2009 price levels.

5.5.2.3 Proposed works and capital cost of tunnel option

Alternative tunnel alignments were considered considering the geology and water table conditions along the tunnel route. The final recommendation comprised a 3 meter diameter tunnel of 9.7 km length, a gravity pipeline of 2.7 km length and inlet and outlet structures. The total construction cost was estimated at R391 million at January 2009 price levels.

5.5.2.4 Operating and maintenance costs

The cost of electrical energy was found to be the major operational cost component of the pumping option. Other operational costs, such as employment of operators, were considered to be similar for both options. Standard percentages on civil and mechanical/electrical component costs were used to estimate annual maintenance costs.

An average (maximum) annual energy use of 20532 megawatt hours (MWh) was estimated by assuming pumping at 3.12 m^3/s against a median hydraulic head of 60.34 meters (TCTA, 2009:10). Applying the 2008/9 Megaflex and Night Save Rural tariff structure of the supplier Eskom, and an expected 40% hike in tariffs (2009:21), an annual cost of R 7415000 was determined for comparative purposes.

5.5.2.5 Economic comparison

Cash flow analyses for the three cases, pumping intermittently, pumping continuously and conveying by tunnel were undertaken over a period of 50 years. Discount rates of 6%, 8% and 10% per annum (p.a.) were applied to obtain the present values (PVs). It was argued that it was not necessary to calculate Unit Reference Values (URVs) as the volumes to be transferred by the two projects were the same.

The results of the economic analyses are summarised in Table 5-3 (TCTA, 2009:23). More detail is provided in ANNEXURE 5-A to ANNEXURE 5-C.

Table 5-3: Comparison of options (2008 base year)

	Present Value (R million) at discount rate		
	6%	8%	10%
Pumping intermittently	363.07	323.03	295.49
Pumping continuously	395.03	346.68	313.39
Gravity tunnel	385.51	368.80	355.00

5.5.2.6 Study recommendations

The TCTA study found that the pumping option is the preferred alternative, even if the electricity prices were to be raised more substantially. While other factors, such as the time required to implement the different options, were also considered, the economic cost comparison was the primary reason for the final recommendation to implement the pumping alternative.

5.5.3 Discussion and evaluation

The TCTA study assumed that a shortage of water would occur every year in the future and that this would have to be made good by transfers from either the Spring Grove Dam (limited by the yield of this dam) – for the continuous case – or the Spring Grove Dam and the future Mkomazi dams – for the intermittent case. The shortage to be met was estimated by subtracting the available yield, before inclusion of the Spring Grove Dam, from the total water requirement. While a systems analysis had been conducted earlier, which provided information on the increase in system yield to be expected from the inclusion of the MMTS-2, no specific analysis was done to investigate the characteristics of water transfers.

As can be seen from Figure 5-2 and ANNEXURE 5-A and ANNEXURE 5-B, the TCTA study envisaged that the water transfers and the electricity costs associated with transferring the water (in the case of the pumping alternative) would not vary much from year to year, except for the changes envisaged in the intermittent case due to the two Mkomazi River dams envisaged in the future which then would be used preferentially.

For comparative purposes the standard economic method of net present value determination, discounting future streams of fixed and variable costs, was applied. For electricity costs the 2008/9 Eskom tariffs were used, which meant it was effectively costed at an average price of 31.1 c/kWh. No shadow pricing was attempted.

In conclusion: the appraisal approach followed in RSA Case 1 is evaluated against the criteria of paragraph 5.3 as follows:

a) Although a full system analysis with the inclusion of the proposed IBT project was undertaken it did not include a simulation of annual operational decision-making and a time-series analysis of likely water quantities to be transferred
b) The assumption was made that all incremental demand, beyond the yield capability of the existing system, had to be supplied from the Spring Grove Dam and/or the subsequent Mkomazi River dams.

The approach followed in the RSA Case Study 1 was therefore analogous to the Incremental Approach described in Chapter 1.

5.6 RSA Case Study 2: Mkomazi-Mgeni Transfer Scheme

This case study examines the appraisal process applied during the investigation into the Mkomazi-Mgeni IBT.

5.6.1 Background

The Mkomazi-Mgeni transfer scheme was investigated by the Department of Water Affairs and Forestry as possible scheme to augment the resources of the Umgeni Water supply area. In July 1997 the Department, in conjunction with Umgeni Water, appointed the firm Ninham Shand to undertake a pre-feasibility study to select a preferred layout and configuration of an IBT from a number of possibilities identified in earlier studies, for further analysis. The investigation was done in two parts; a reconnaissance part first, followed by the pre-feasibility study, completed in May 1999 (DWAF, 1999a).

The Mkomazi River was envisaged to have the potential to make a significant contribution to the Mgeni River System. Two major dam options, one at Impendle and the other at Smithfield, were examined in detail, as were the possible transfer routes. From Impendle Dam it was envisaged that water can be conveyed by gravity tunnel to the Mgeni River above Midmar Dam, while water from the Smithfield Dam could be transferred by pumping into a tunnel that would link it to the water supply system of Umgeni Water.

Figure 5-3 shows the locality of the Mkomazi catchment and the possible dams mentioned in relation to the Mgeni catchment with its existing dams as well as the Spring Grove Dam on the Mooi River (MMTS-2) that also would augment the Mgeni system and the construction of which, at the time of the investigation, had not started.

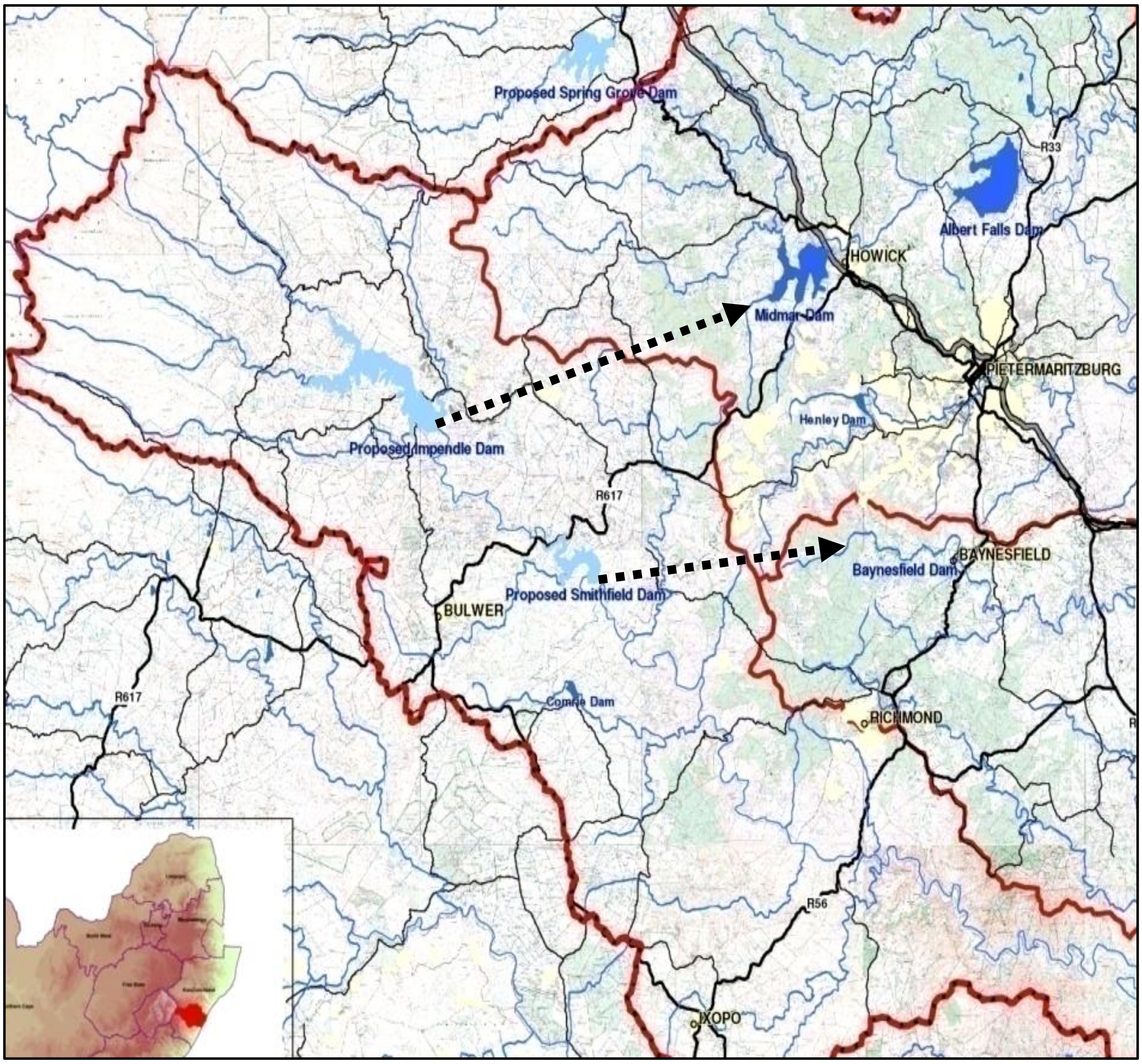

Figure 5-3: Proposed dams on the Mkomazi River and possible conveyance routes to the Mgeni basin (Adapted from BKS, 2012)

5.6.2 Summary of investigation

This section summarises the investigation and its findings.

5.6.2.1 Yield assessments and quantities required to be transferred

The investigation projected high, medium and low water demands for the Mgeni system as shown in Figure 5-4. The medium projection was considered the most likely.

The net demands to be met by the proposed transfer schemes were calculated by subtracting 397 million m^3 per year, being the 1:100 yield estimate of the Mgeni System (inclusive of Midmar Dam raising and MMTS-2), from the medium projection. (DWAF, 1999a:24). Transfers were assumed annually to be equal to the incremental demand capped by the incremental yield associated with a specific option.

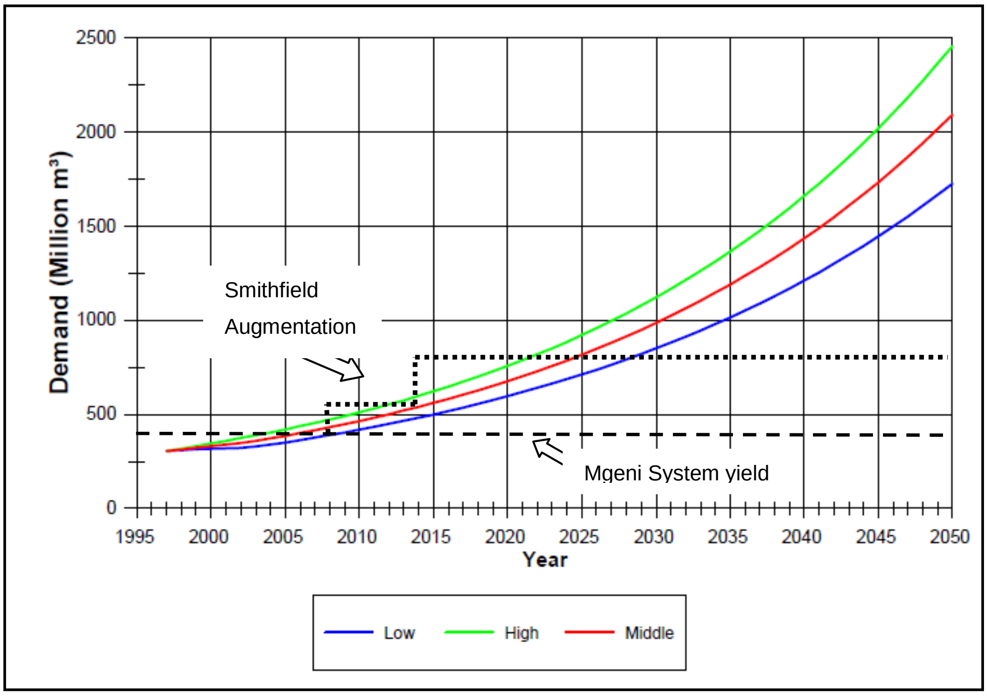

Figure 5-4: Water demand projections for the Mgeni system (adapted from DWAF, 1999a:24)

During the pre-feasibility phase of the study (see par 5.6.2.2 below) the WRYM model was used to obtain the long-term yields of each of the Mkomazi augmentation options. Consideration was given to future water requirements that may arise within the Mkomazi basin and only the net yield was assumed available in the long run. The 1:100 yields were used in the project selection.

5.6.2.2 Project selection

Eight schemes were selected during the project-identification phase. These comprised dams at four different sites and different routing for the transfer conveyance structures. Three schemes were eliminated during the initial screening process for reasons of insufficient yield or excessive pumping head. The remaining five were further examined and costed. As these were found to be quite close in costs, all five were carried through to the pre-reconnaissance phase where a further two schemes were eliminated, one primarily for environmental impact reasons and the other for environmental as well as high pumping cost reasons. A further one was eliminated during the reconnaissance phase for economic reasons.

The remaining two options were the Impendle Dam with a conveyance tunnel to Midmar Dam, and the Smithfield Dam with a conveyance route to Baynesfield to link into the Mgeni system. As the Smithfield site cannot accommodate a very large dam, this option also included the larger Impendle Dam as a later second phase (without its tunnel).

During the pre-feasibility phase, detailed costing of the two remaining options was undertaken. It was found that the Smithfield Dam option, with its conveyance system to Baynesfield, was more economical than the option of the Impendle Dam and its tunnel to Midmar.

The Smithfield Dam option comprises, as a first phase, a dam of 137 million m^3 capacity, an intake structure and pumping station in the dam to pump 7 m^3/s, against an average head of 48 meters into a 32.9 km tunnel to the Baynesfield Dam on the Mlazi River. The second phase would entail the building of the 830 million m^3 Impendle Dam and increasing the pumping capacity to 16.2 m^3/s.

The estimated 1:100 year long term stochastic yields of the two phases of the Smithfield Dam option were 147 million m^3/a and 376 million m^3/a respectively (DWAF, 1999a:36). It was envisaged that the first phase would start to deliver water in 2008 and the second phase in 2014 as illustrated in Figure 5-4 above.

5.6.2.3 Economic methodology applied during project selection

In all of the stages of the investigation the same methodology was used to select preferred projects; cost estimates were based on August 1997 prices and projected over a 50 year economic life – from 2008 to 2053. Electricity costs were based on the “Miniflex” tariff schedule of Eskom.

The resultant costing streams were discounted at 6%, 8% and 10% p.a. to obtain PVs. These values were then divided by the present value of the water delivered to obtain URVs for each scheme at each of the three discount rates (DWAF, 1999a:10). The URV calculations were considered necessary as the different options had different yields and would deliver different quantities of water to the Mgeni system over their lifetimes (1999a:56).

ANNEXURE 5-D provides an example of the costing stream and the resultant URV for one of the options; the Smithfield to Baynesfield option (DWAF, 1999b:Appendix C).

5.6.3 Discussion and evaluation

The pre-feasibility investigation into the options to augment the Mgeni from the Mkomazi by means of a transfer scheme examined a wide range of options and, taking into regard a number of criteria and through a cascade of screenings, reduced the options to a single preferred one for feasibility investigation. The investigators assumed that a shortage of water would occur every year in the future and that this would have to be made good by transfers from the Mkomazi basin. The shortages to be met were estimated by subtracting the available yield, before inclusion of the Mkomazi IBT project, from the total water requirement.

System yields were determined for the Mkomazi system, in order to obtain accurate estimates of the maximum potential quantities of water that could be transferred to the Mgeni system. No integrated analysis was undertaken of the two systems joined by the IBT.

As can be seen from ANNEXURE 5-D the study envisaged that the water transfers and the electricity costs associated with transferring the water would not vary much from year to year. For comparative purposes the URV measure was determined by discounting future streams of fixed and variable costs and dividing them by the discounted water transfers. For electricity costs the 1997 Eskom tariffs were used. No shadow pricing was attempted.

In conclusion: the appraisal approach followed in RSA Case 2 is evaluated against the criteria of paragraph 5.3 as follows:

a) A full system analysis with the inclusion of both the receiving basin and the proposed IBT project was not undertaken and therefore no simulation was done of annual operations and likely water quantities to be transferred
b) The assumption was made that all incremental demand, beyond the yield capability of the existing system, had to be supplied from the Mkomazi River dams.

The approach followed in the RSA Case Study 2 was therefore analogous to the Incremental Approach described in Chapter 1.

5.7 RSA Case Study 3: Crocodile-Mokolo Transfer Scheme

This case study examines the appraisal process applied during the investigation into the Crocodile-Mokolo IBT.

5.7.1 Background

The Mokolo Dam was built some thirty years ago south-east of Lephalale (previously Ellisras) on the Mokolo River, a tributary of the Limpopo River, to supply water to the Grootegeluk coal mine and Matimba – Eskom's first large dry-cooled power station. Irrigators downstream and the Lephalale town also received water from the dam (DWA, 1979:3-5). The dam, with its gross storage capacity of 145 million m^3, or 68% of the mean annual runoff (MAR), still remains today the only major impoundment in the Mokolo River catchment (DWA, 2010b:1-1). Not much further development on the extensive Waterberg coal deposit has happened in the intervening period, but, as the focus of coal-based developments has shifted from the Witbank-Highveld coal fields of Mpumalanga to the Waterberg, matters are due to take a dramatic turn, with significant consequences regarding water supplies to the area.

An increase in water demand will occur soon when the 4800 megawatt Medupi Power Station, currently under construction, comes on stream. This will be followed by further increases in water requirements as more coal-fired power stations, coal-based industries and mines are developed and urban growth follows. To investigate the options of water supply to the area the DWA embarked on a detailed study in 2008. The Mokolo and Crocodile (West) Water Augmentation Project (MCWAP) study was undertaken in two phases; a pre-feasibility first phase, followed by the feasibility phase (DWA, 2010b).

Although some unutilised yield remained in the Mokolo Dam it was soon clear that this could, at best, only meet the needs for a few years before more water supplies would be required. It was also soon realised that, with limited opportunities for further development of resources in the Mokolo River catchment remaining, options to import water from other catchments had to be investigated. In this regard the Crocodile River, a much larger tributary of the Limpopo River, was the obvious direction in which to turn. Despite the resources of the latter river already being highly developed, large return flows from its upper catchment – fed with water from the Vaal River System (see Figure 1-4) – augment the resources of the Crocodile River to the extent that transfer schemes would be able to meet some, if not all, of the shortfalls of the Mokolo System.

The proposed project is shown schematically in Figure 5-5. Phase 1 of the project would consist of pumping stations and pipelines to transport the available yield of the Mokolo Dam to the centres of demand, while the second phase would consist of the abstraction and appurtenant works in the Crocodile River, and pumping stations and pipelines to connect to the phase 1 infrastructure.

This review focuses on the appraisal method employed for the selection of the option of transferring water from the Crocodile River.

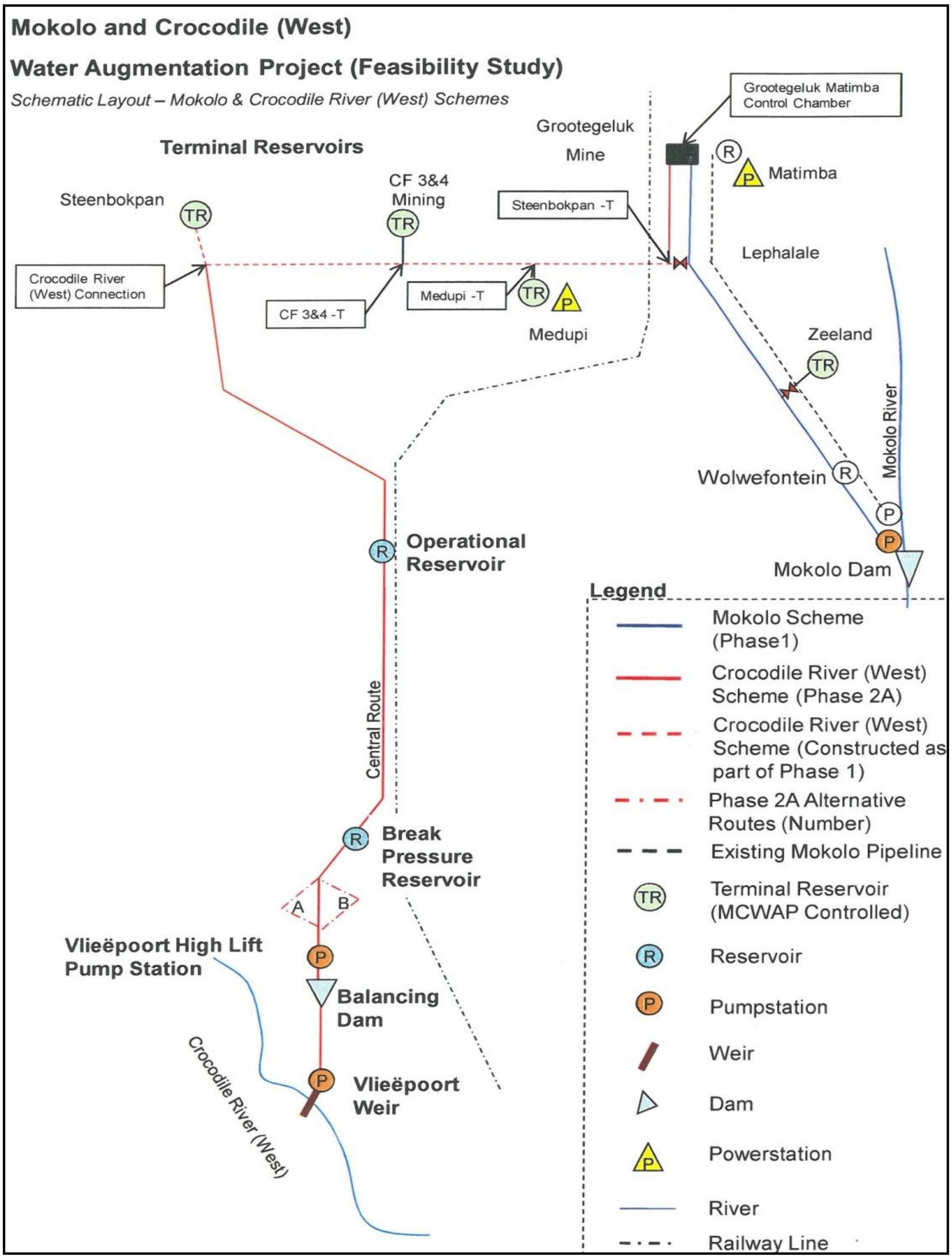

Figure 5-5: Schematic layout of the Mokolo and Crocodile (West) Water Augmentation Project (DWA, 2010a:1-2)

5.7.2 Summary of the investigation

The projected MCWAP water requirements, the water resource availability as assessed, the options to meet the requirements and the methodology employed to select the best option are described in the following paragraphs.

5.7.2.1 Water requirements

The MCWAP study experienced difficulties in constructing reliable growth scenarios; the situation kept on changing as the expectations of some of the developments to come about, e.g. SASOL's Mafuta coal-to-liquid (CTL) plant, waxed or waned. Contributing uncertainties revolved around whether or not the power stations, including Medupi, would require flue gas desulpherisation (FGD) facilities and the policy direction of the country regarding further coal-based power generation, as opposed to other lower carbon emission types of generation such as nuclear power.

A number of development scenarios and their resultant water requirement projections until the year 2030 were generated. Scenario 9, shown in Figure 5-6, illustrates the rapid growth foreseen due to the following possible developments (DWA, 2010a:3-3 to 3-4):

a) A further four coal-fired power stations by Eskom and one by an independent power producer, to follow the two Eskom power stations, Matimba and Medupi
b) Additional coal mines to supply the power stations
c) A SASOL CTL plant, called Mafuta 1, plus its mine in the Steenbokpan area
d) Increased domestic water requirements due to the development in the area.

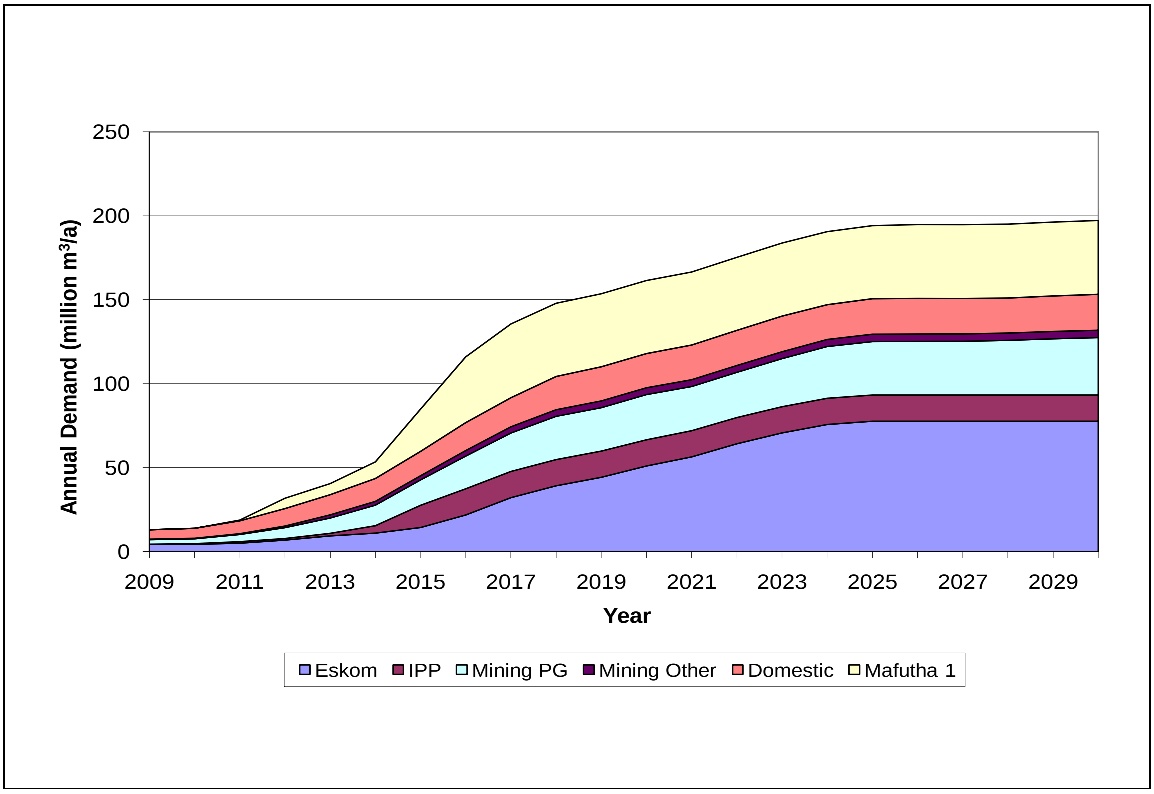

Figure 5-6: Scenario 9 water requirements (DWA, 2010a:3-3)

For the purpose of this study the analyses undertaken on the basis of the water requirement growth scenario 8 were reviewed. The latter scenario is only marginally different to scenario 9, especially in the initial years, as illustrated in Figure 5-7 (DWA, 2010a:3-2).

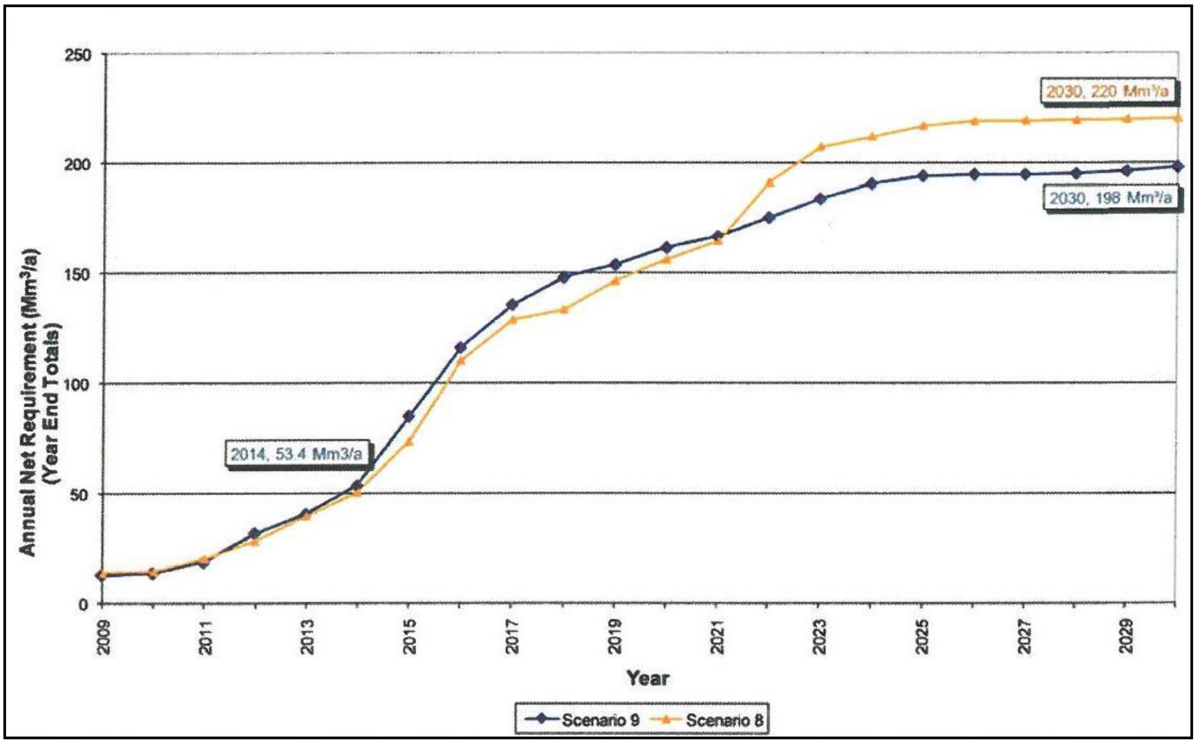

Figure 5-7: MCWAP: Comparison between Scenario 8 and Scenario 9 water requirements

5.7.2.2 Project description

Fourteen options were investigated for transferring water from the Crocodile River to the Mokolo River catchment. These options included two growth scenarios, one of which was Scenario 8, two abstraction points along the Crocodile River and a number of routes to transport the water (DWA, 2010c:5-4). As the same methodology was used for all the options, only one, option 5 in this case, is reviewed.

Option 5 (with the identity 8-P2-TVCB1-DB1) assumed Scenario 8 water requirements and comprised, as illustrated in Figure 5-5 above, the following elements (DWA, 2010c:6-15):

a) A river abstraction works at Vlieëpoort consisting of a concrete weir and primary desilting works, a low-lift pumping station with a maximum dynamic head of 40 m, a low-level pipeline and a secondary desilting facility
b) A high-lift pumping station with a maximum dynamic head of 235 m
c) A 2.1 m diameter rising main along the central route of 97.9 km to a balancing reservoir, and
d) A 2.3 m gravity pipeline of 24.8 km, plus link lines to Steenbokpan and Medupi.

5.7.2.3 Hydrology and yields

In 2008 the DWA updated the hydrological record of the Mokolo River catchment in order to improve the assessment of the yield of the Mokolo Dam and to model the system by means of the WRYM and the WRPM packages (DWAF, 2008a and DWAF, 2008b). Natural rainfall, evaporation and stream flow data records were developed for the period October 1920 to September 2004 (DWAF, 2008a:13). Adjusting for abstractions (mainly irrigation) and return flows, the stream flows were brought to current day conditions. The HFY of the Mokolo Dam was consequently determined at 38.7 million m^3/a. Further stochastic analyses, using the WRYM for the entire Mokolo System, indicated the 1 in 200 year yield – the assurance level adopted for water supply to power stations – of the Mokolo Dam as being 39.1 million m^3/a (2008a:79). Allowing for a 10.4 million m^3/a downstream irrigation requirement, the available yield from the Mokolo Dam for industrial, mining and municipal supplies was determined at 28.7 million m^3/a.

As regards the Crocodile system, a number of water balances were conducted earlier with different scenarios of growths and return flows, affected by urbanisation and water demand management measures. In Figure 5-8 the water balance situation for a relatively high return flow projection in the Crocodile River catchment is shown against the range of MCWAP demand scenarios, one of which is Scenario 8 (DWA, 2010d:2-2 and A1). Note that the surplus yield of the Crocodile River was envisaged, initially, to reduce due to the introduction of water demand measures in the source-catchment as well as due to proposals to re-use some of the return flows to meet mining water requirements upstream within the basin. All the scenarios that included the SASOL Mafuta CTL plant, such as Scenario 8, showed shortages which, it was envisaged, had to be made up by transfers from the Vaal River to the Crocodile River system (DWA, 2010d:2-3).

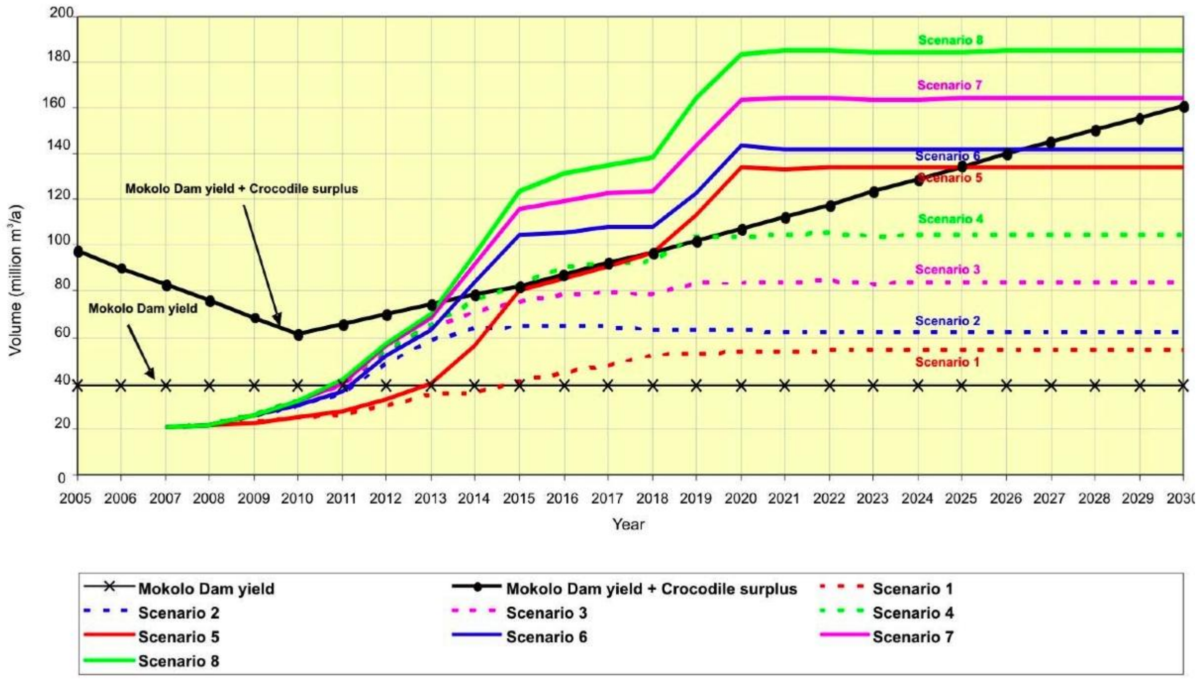

Figure 5-8: MCWAP water balance for scenario of high population and medium demand management

To assess the situation in the interim, before augmentation could be effected from the Crocodile River, the WRPM was used to analyse the yield availability of the Mokolo Dam with dynamic growth in water requirement and the timing of first water transfers from the Crocodile River. It was found that assurance levels would be met, provided water transfers are in place by August 2014 (DWA, 2010d:3-6).

5.7.2.4 Water transfers

The Scenario 8 projected water requirements from the two phases of the MCWAP from the year 2008 to the year 2060 is provided in ANNEXURE 5-E and represented in Figure 5-9. Note that the capacity of the second phase is limited to a net water supply of 219.95 million m^3/a and that, while the safe yield of Mokolo Dam is 28.7 million m^3/a, this yield figure will be exceeded in the short term until the second phase is fully operational in 2015 (DWA, 2010c:6-8 to 6-9).

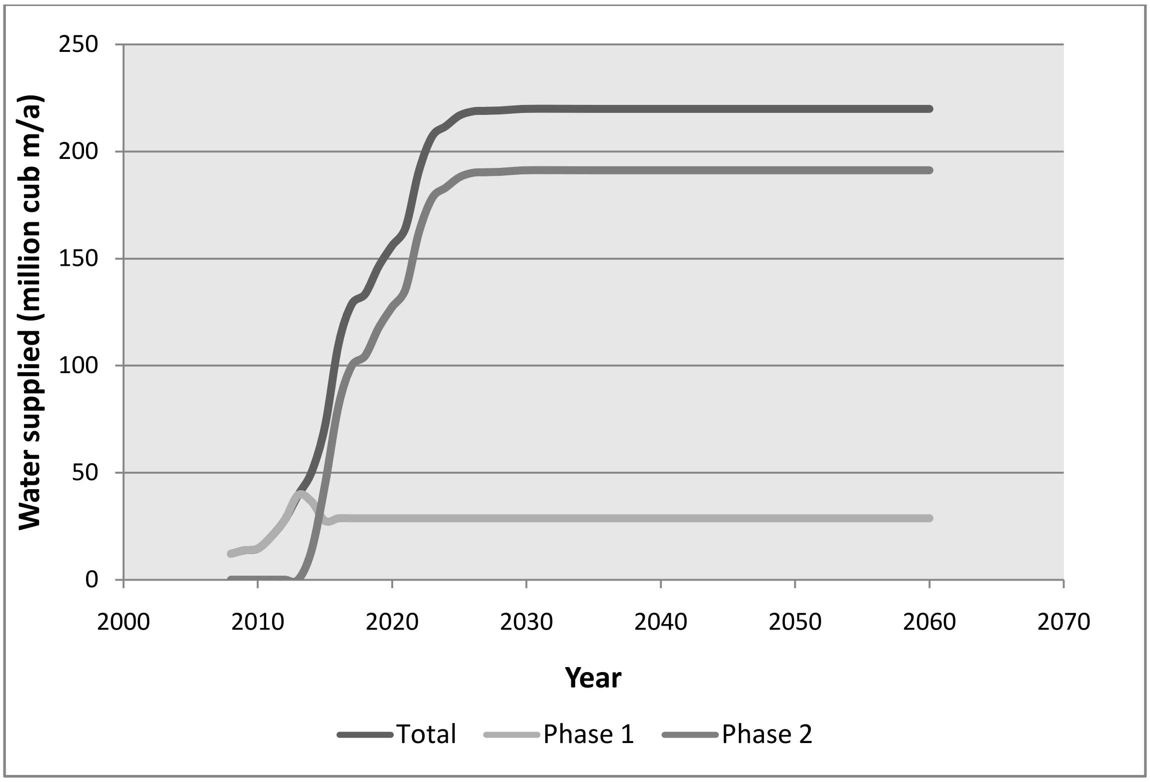

Figure 5-9: MCWAP Scenario 8: Net water requirements from Phases 1 and 2

5.7.2.5 Appraisal methodology for option selection

The Phase 2 water requirements were used to assess the viability of Option 5 (described in paragraph 5.7.2.2). An in-depth analysis was undertaken to determine the initial capital cost of the option as well as the annual costs comprising operation, maintenance and replacement cost over the economic analysis period 2008 to 2060. Electricity costs and raw water costs formed the variable portion of the annual operating costs.

Electricity costs were based on Eskom Megaflex tariff structure in 2008, escalated at 20% per annum over the first five years, while the raw water costs were based on the DWA tariffs for water in the Mokolo and Crocodile Systems respectively. The raw water cost, taking into account river losses, was determined at R1058.1 million/a from 2030 onwards with the system running at full operation. The annual electricity cost, from 2030 onwards, was determined at R79.7 million (DWA, 2010c:6-6 to 7-4) as shown in ANNEXURE 5-F. The URV methodology was used to select the best layout: “The scheme with the lowest URV (the lowest average total life-cycle cost per unit of water delivered) provides the most benefit for the funds employed in constructing, operating and maintaining the scheme” (DWA, 2010c:6-1). The URV for Option 5 was determined by discounting the projected total costs over all the years to a present value at 2008 and by dividing it by the water transfers, similarly discounted over the same period. The sensitivity for the choice of the annual discount rate was tested by doing it for three rates; 6%, 8% and 10%. The results are shown in Table 5-4 and Table 5-5.

Table 5-4: MCWAP 2: Discounted Present Values for Option 5

Discount rate	Capital (Rand million)	O&M (Rand million)	Total (Rand million)
6%	8412.54	11764.28	20176.81
8%	7905.90	8035.56	15941.46
10%	7441.84	5742.63	13184.47

Table 5-5: MCWAP2: URV for Option 5

Discount rate	**Discounted value**		
	Total water delivered	Life-cycle costs	URV
	Million m^3	Rand million	R/m^3
6%	2 148.85	20176.8113	9.39
8%	1 484.20	15941.45995	10.74
10%	1 073.36	13184.47252	12.28

5.7.3 Discussion and evaluation

The Mokolo and Crocodile (West) Water Augmentation Project (MCWAP) study examined the options to supply the developments expected on the Waterberg coal fields. Various scenarios of growth were postulated on the basis of which a wide range of options to meet the resultant requirements was investigated.

The hydrology of the Mokolo River as well as the Crocodile River were previously analysed and that information was used in the MCWAP study. Separate systems analyses were conducted to ascertain the available water in the two systems. Costing was done and the results were used to obtain the URV of each option, on which basis recommendations were made for further implementation.

Variable costs associated with the transfers of water from the Crocodile River system were related directly to the shortfall predicted. The annual shortfalls were determined by subtracting the available yield of Mokolo Dam from the annual water requirements. The study did not undertake an integrated analysis of the two catchments to be joined by the Crocodile-Mokolo IBT. Electricity costs were also not shadow priced –an omission of the investigation.

An issue that comes to the fore from this particular case study is the inclusion of raw water costs in the variable operating costs, i.e. payments for water abstracted from the resource. These costs are very high, as can be seen from paragraph 5.7.2.5, and have a considerable influence on the URV calculations. While it was argued that the raw water cost in the Crocodile River should be viewed as a proxy, in the absence of more precise cost calculations, of capital and operating costs that would be required to augment the Crocodile River from the Vaal River System to the south of the catchment (DWA, 2010b:4-2 and DWA, 2010c:6-12), this seems a mixed proposition as water cost proxies would not be required for abstracting water from the Mokolo Dam. It would seem rather, therefore, that these costs, or parts thereof, were erroneously included; erroneously as these constitute transfer[8] costs similar to VAT – which correctly were not included in the economic model. In the light of the dominating effect of the raw water costs it would have been pertinent to examine the requirement for, and costs of, augmentation from the Vaal River System in greater detail.

In conclusion: the appraisal approach followed in RSA Case 3 is evaluated against the criteria of paragraph 5.3 as follows:

a) A full system analysis with the inclusion of both the receiving basin and the proposed IBT project was not undertaken. No simulation was accordingly done of annual operations and likely water quantities to be transferred
b) The assumption was made that all incremental demand, beyond the yield capability of the existing system, had to be supplied from the Crocodile River, being the new proposed resource.

The approach followed in the RSA Case Study 3 was therefore analogous to the Incremental Approach described in Chapter 1.

5.8 RSA Case Study 4: Thukela-Vaal Transfer

This case study examines the appraisal process applied during the investigation into the Thukela-Vaal IBT.

5.8.1 Background

In the early 1990s, as part of the wide ranging study by the (then) DWAF to identify the best options to augment the Vaal River System, called the VAPS, an investigation was conducted at pre-feasibility level into possible transfers from the Thukela River basin to the Vaal River basin. The TVTS would have provided transfers additional to those of the existing Drakensberg Project, described in paragraph 4.4.1 (DWAF, 1994).

Seventeen possible layouts were analysed in the VAPS-TVTS study. Capital costs and running costs over the design lives of the schemes were discounted to present day costs and their URVs calculated. Four layouts were recommended for further analysis. One of these made use of Eskom’s Drakensberg pumped storage hydro-electric facility. It involved a large dam on the Thukela River below Spioenkop Dam at a site called the Klip, a dam on the Bushmans River, a tributary of the Thukela at a site called Mielietuin, and conveyance

[8] Economically speaking – not to be confused with water transfer costs.

infrastructure to connect the two proposed dams to the existing Kilburn Dam. The other three options involved new pumped storage facilities, similar to the Drakensberg Project, at sites called Waayhoek and Chatsworth, and therefore were dependent on Eskom's interest in (another) such joint project with the department (DWAF, 1994:10-13).

The Thukela Water Project (TWP) feasibility study was a follow-up study of the VAPS TVTS. Apart from identifying the most feasible option, the study was also intended to provide information to allow comparison with the second phase of the LHWP, both projects having been candidates for the next project to augment the Vaal River system.

The economic justification of the project was a primary focus. The preferred scheme comprised the Jana Dam in the main stem of the Thukela River and the Mielietuin Dam on the Bushmans River and aqueducts to transfer 15 m^3/s to the existing Drakensberg pump storage scheme as shown in Figure 5-10 (DWAF, 2001c:1).

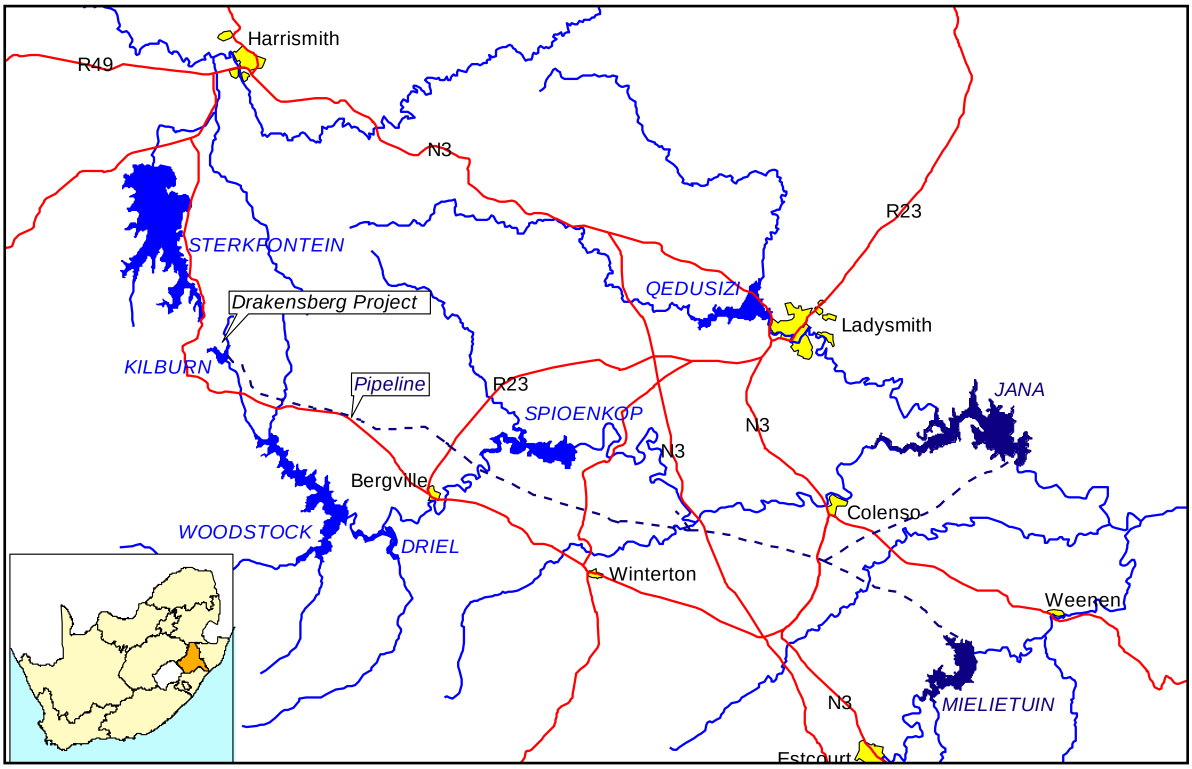

Figure 5-10: TWP: Proposed Jana and Mielietuin Dams and pipelines to the Drakensberg Project

To compare the TWP proposals with the proposed second phase of the LHWP, a study, called the *Vaal River Water Resource Development Project: Comparative Study between*

LHWP II and Thukela Water Project[9], *was* commissioned by the DWA and completed in 2010 (DWA, 2010e).

In the feasibility study it was proposed that the TWP include the following elements:

a) The 160m high concrete gravity Jana Dam on the Thukela River with a capacity of 1500 million m^3
b) The 97m high concrete arch Mielietuin Dam on the Bushmans River with a capacity of 350 million m^3
c) A pumping station at Jana to pump 11 m^3/s against a static head of 357m and its 2.5m diameter rising main of 25.6 km
d) A pumping station at Mielietuin to pump 4 m^3/s against a static head of 131m and its 1.0m diameter rising main of 19.6 km to meet with the pipeline from Jana
e) Two further pumping stations against a total static head of 234m to convey 15 m^3/s to Kilburn Dam by means of a 76.4 km pipeline of diameter varying between 3.0 and 3.1m (DWAF, 2001a:8-1).

The four pumping stations required a combined estimated power supply of 90 MW. To this had to be added the power requirement at the Drakensberg hydroelectric pumped storage plant to convey the water against a static head of 440 m from Kilburn Dam to Sterkfontein Dam.

In the *Comparative Study* a larger Jana Dam, 190m high with a capacity of 2650 million m^3, and with a transfer capability of 12.55 m^3/s, was considered for the D3L4High scenario described in the next paragraph.

5.8.2 Summary of the investigation

This section summarises the investigation and its findings.

5.8.2.1 Water requirements and yields

A large number of water requirement scenarios were investigated in a study conducted by the DWAF, called the Reconciliation Study for the Vaal River System. Variables related to the population growth, developments in the Lephalale area, some requiring export from the Vaal River system to the Crocodile-Mokolo system, the re-use of mine water and waste water effluent within the Vaal Supply area, as well as various water conservation and demand management (WC&DM) interventions, brought the total number of possible scenarios in the Reconciliation Study to 96 (DWAF, 2008c:50).

[9] Henceforth referred to as the *Comparative Study.*

The *Comparative Study* used only four of the demand scenarios; it assumed a 15 % water saving from WC&DM measures, two population growths (high and “base”), and whether the next SASOL CTL plant to be either in the Lephalale area, or below Vaal Dam (DWA, 2010g:3-4).

To balance the demands with supplies from the TWP, different sizes of the two dams, Jana and Mielietuin, were used. The net HFYs, after allowing for the ecological water requirement (EWR), are summarised in Table 5-6 (DWA, 2010e:5).

Table 5-6: Net Yields of TWP dam options

Scheme	Dam	Size	Net HFY (million m^3/a)
TWP	Jana	840m FSL (small)	**293**
		860m FSL (medium)	**325**
		890m FSL (large)	**396**
	Mielietuin	1015m FSL (small)	**112**
		1025m FSL (medium)	**119**
		1033m FSL (large)	**126**

The net yields in Table 5-6 were considered the transferable yields from the two dams. These were determined from systems modelling, using the WRYM, during the feasibility study. Stochastic analyses showed that the assurance levels of the HFYs were in the order of 99% (DWAF, 2001a:7-15).

In order to meet the demands, the dams needed to be introduced timeously, taking account of minimum periods of implementation. The *Comparative Study* used the water balances of six planning scenarios developed in the Reconciliation Study for the Vaal River System involving the TWP. These were developed from simulation modelling analyses of the IVRS using the WRPM (DWAF, 2008c:8).

Figure 5-11 shows one such water balance – the scenario of high population growth, the CTL plant in the Free State and no direct waste water re-use, with identity D3L4High (DWA, 2010g:39). It shows that a large Jana Dam is required by 2018 – the earliest date that it can become operational – followed by a medium Mielietuin Dam later in 2034. It also shows some shortages before 2018, which would require additional measures to deal with, such as some re-use and extra WC&DM measures. This particular scenario, D3L4High, will be used to review the appraisal methodology of this investigation.

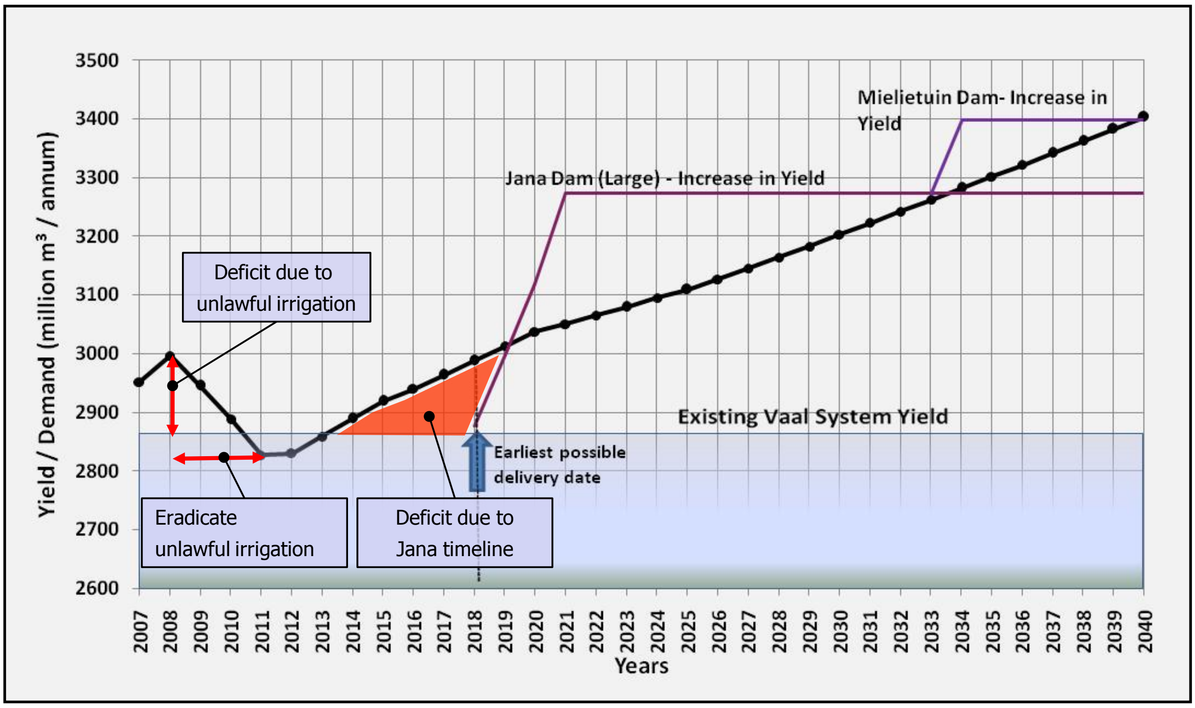

Figure 5-11: Vaal River System water balance: Scenario with high population, CTL in the Free State, and no direct waste water re-use (D3L4High)

5.8.2.2 Water transfers

For the D3L4High Scenario in the *Comparative Study* the annual transfer requirements from the TWP were equated to the projected shortfalls in the Vaal Supply system. The latter were derived by subtracting the system yield from the projected Vaal system demand, capped by the net yield of Jana Dam, as illustrated in Figure 5-12. Detailed figures are provided in ANNEXURE 5-G (DWAF, 2008c:40 and DWA, 2010h:17).

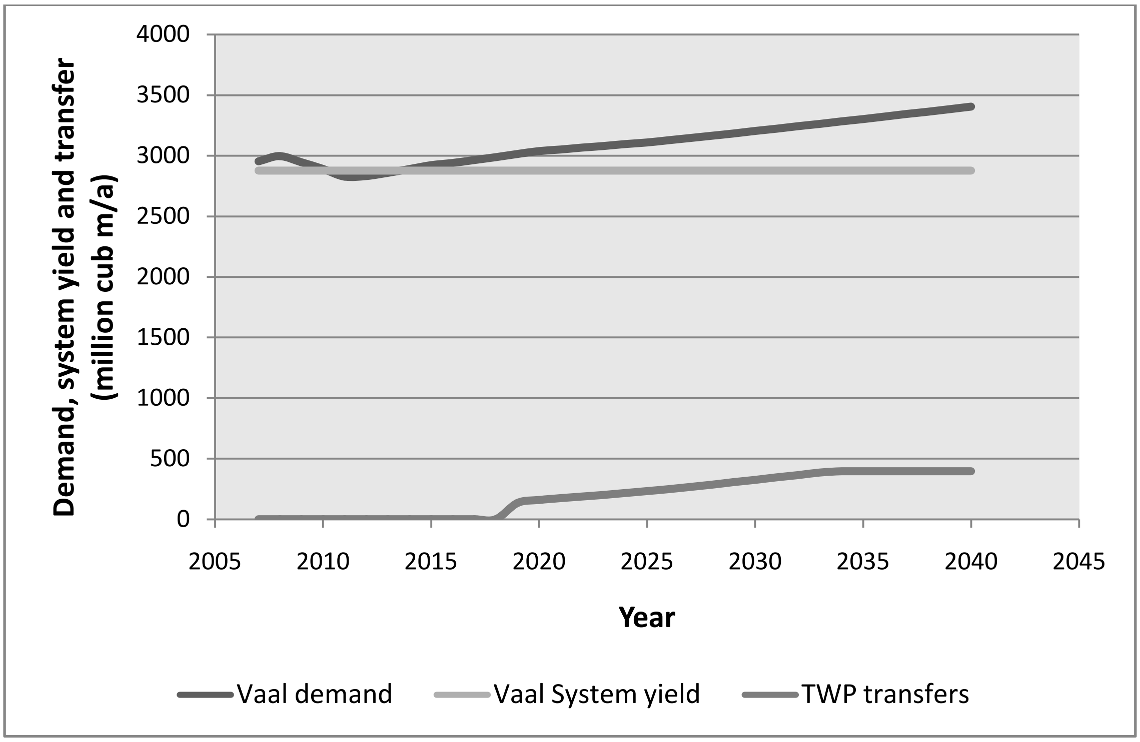

Figure 5-12: Thukela Vaal: Projected transfers

The Vaal River system yield in Figure 5-12 was equivalent to the total supply capability of the system as determined by simulation analysis, using the WRPM and constrained by applicable curtailment risks (DWAF, 2008:59).

5.8.2.3 Costing

In the *Comparative Study* the TWP feasibility costs were updated from March 1998 to October 2007. The total capital cost for Jana Dam, pipelines, pumping stations and advance infrastructure came to R10 143 million, as detailed in Table 5-7 (DWA, 2010h:9). This excluded costs associated with Mielietuin Dam, which did not feature further in the comparative analysis as the yield of the Jana Dam was of the same order as that of the second phase of the LHWP (DWA, 2010e:16-17).

Table 5-7: Thukela-Vaal: Capital cost for Scenario D3L4High

Element	Civil R million	M&E R million
Jana Dam at FSL 890 m AMSL	5728.300	322.400
Pipelines - Jana to Kilburn (capacity of 12,55 m^3/s)	3425.900	0
Pump stations - Jana to Kilburn (Capacity 12,55 m^3/s)	88.400	395.800
Roads	182.144	0
Total	9424.744	718.200

Electricity costs for pumping to Kilburn Dam were assessed at Eskom's non-municipal Megaflex electricity charges effective from 1 July 2008. The costs to transfer the water through the Drakensberg pumped storage facility were assessed from Eskom's Wholesale Electricity Pricing System (WEPS). For other operating and maintenance costs, standard percentages of capital costs were applied (DWAF, 2010e:19).

5.8.2.4 Economic methodology applied

The URVs for Scenario D3L4High (as for all the other scenarios) were established from the discounted life-cycle cash flows and the water augmentation over a period of 40 years. Real discount rates of 6%, 8% and 10% were used. Capital costs were evenly distributed over five years, starting in 2014. Mechanical and electrical components were replaced after 30 years and residual values were credited at the end of the analysis period, i.e. the year 2058.

The electricity cost, at transfer from the TWP of 396 million m^3/a, was calculated at R224.14 million/a. This cost was proportioned according to transfer requirements depicted in Figure 5-12 to derive the annual electricity costs for Scenario D3L4High (see ANNEXURE 5-H for detail).

The resultant URVs for Scenario D3L4High are shown in Table 5-8.

Table 5-8: Thukela-Vaal: Derived URVs

Discount rate	6%	8%	10%
URV (R/m^3)	3.97	5.31	6.94

5.8.3 Discussion and evaluation

This case study revealed that:

a) The availability of water in the receiving catchment was determined by systems simulation of the IVRS – as it existed at the time. This was called the Vaal River system yield

b) The transferable water from the Thukela River was based on systems analyses of the Thukela System with the inclusion of the proposed scheme, consisting of the Jana and Mielietuin Dams. The HFYs were considered suitable for this purpose as the stochastic hydrological analyses showed the HFYs provide required levels of assurance

c) The projected quantities of water to be transferred annually were assumed to be equal to the shortfalls in the IVRS, i.e. the Vaal River system demands from which were subtracted the system yield, capped by the yield of the Jana Dam. (The Mielietuin Dam yield was not required for comparison with the second phase of the LHWP.)

d) Pumping costs were derived directly from the quantities to be transferred
e) For electricity costs the 2008 Eskom tariffs were used. No shadow pricing was attempted.

In conclusion: the appraisal approach followed in RSA Case 4 is evaluated against the criteria of paragraph 5.3 as follows:

a) A full system analysis with the inclusion of both the receiving basin and the proposed IBT project was not undertaken. No simulation of annual operations and likely water quantities to be transferred was accordingly performed
b) The assumption was made that all incremental demand, beyond the yield capability of the existing system, had to be supplied from the Thukela System.

It is thus concluded that the approach used in this case study was completely analogous to that of the Incremental Approach described in Chapter 1.

5.9 International Case Study 1: The Wanjiazhai Water Transfer Project (First Phase) in the People's Republic of China

This case study differs from the previous ones in that it assesses the World Bank's appraisal approach by reviewing two linked reports; a pre-project appraisal and an *ex post facto* evaluation.

5.9.1 Background

In the mid 1990s the Government of the People's Republic of China requested the World Bank to assist in the financing of the Wanjiazhai Water Transfer Project (WWTP) to augment water supplies in its Shanxi Province. In 1997 the World Bank completed a Staff Appraisal Report (SAR) of the proposed WWTP to confirm the feasibility of the project (World Bank, 1997). In 2007, two years after completion, the World Bank undertook an Implementation Completion and Results (ICR) investigation (World Bank, 2007).

The WWTP represented an important first step towards China's water resource planning proposals of mega water transfer projects from the Yangtze River in the south via the Yellow River Basin to the water scarce north (Xie, Guo and Ludwig, 1999:40).

The Shanxi Province lies in the northeast of China within the larger Yellow River basin. The climate is semi-arid with a mean annual precipitation (MAP) of 525 mm, but rainfall can be as low as 400 mm/a in the northwest of the province. Northern Shanxi was highly industrialised, with many water-intensive, mostly coal-based industries in and around its capital, Taiyuan City. The area experienced high growth in the decades after 1978 with commensurate growth in water requirements. By the early 1990s the local water resources were no longer able to meet the demands, which meant that further growth was constrained due to a lack of secure water supplies (World Bank, 1997:1-3).

The Fen River (also called Fenhe), a tributary of the Yellow River, runs roughly north to south through the Shanxi Province. Together with groundwater the river had been the source of water for the development of the area. By the 1990s severe over-abstraction of groundwater occurred and irrigators were only secured of a small portion of their requirements.

The rainfall in the area exhibits relatively high inter and intra annual variability. This variability is reflected too in the surface water runoff; in the upper Fen River the long term mean annual runoff (MAR) was measured as 127 million m^3/year before 1970, but only 47 million m^3/year between 1988 and 1993. This sharp decline was also attributed to over-abstraction of the ground-water resources as well as land-management practices in the upper catchment (World Bank, 1997:6).

The first phase of WWTP, to transfer water from the Yellow River basin to the Fen River basin, was constructed at a total cost of US$1070 million (World Bank, 2007:17). Construction started in 1998 and the project was completed in 2005. It comprised tunnels of a total length of 144 km and five pumping stations to overcome a total static head of 648 meters. The source of water was the Wanjiazhai Dam, a dam constructed concurrently on the Yellow River, from which water is conveyed to the delivery point in the upper reaches of the Fen River, some 66 km upstream of the Fen Dam (the latter built in the 1960s with a capacity of 700 million m^3 and an active storage of 385 million m^3). Twin pipelines of 40 km length, and a 17km tunnel, linked the dam to Taiyuan City, the main point of delivery (World Bank, 1997:19-23). A northerly branch of the WWTP was planned to link the Sang-Kan River Basin and Datong City to the north, at a later date (see Figure 5-13).

The transfer capacity of the WWTP First Phase to Taiyuan City was designed for 640 million m^3/a (25.8 m^3/s), but the installed pumping capacity first limited to 320 million m^3/a (12.5 m^3/s) (World Bank, 1997:22).

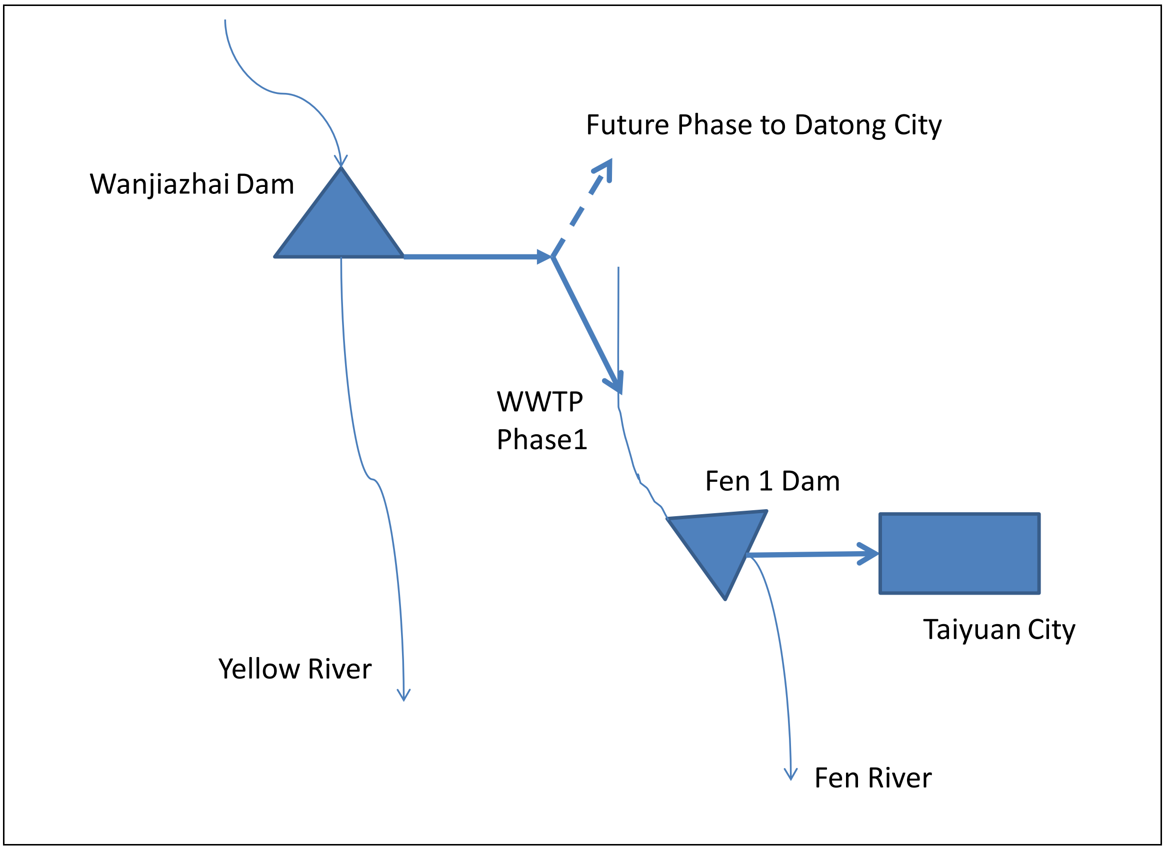

Figure 5-13: Schematic layout of the Wanjiazhai Water Transfer Project

5.9.2 Summary of SAR investigation

This section summarises the investigation and findings of the initial appraisal of the WWTP.

5.9.2.1 Yield and water requirements

The surface water yield, at a 75% level of assurance, of the upper Fen River system supplying the Taiyuan area was estimated to be 180 million m^3/year. Taking into account a sustainable abstraction of groundwater, the total sustainable local water resource (combined ground water and surface water) was estimated at 487 million m^3/year at a 75% level of assurance (World Bank, 1997:5-10). The sustainable resource (all being groundwater) for municipal and industrial (M&I) use was estimated at 272 million m^3/year (1997:165).

The SAR also investigated the availability of water from the source catchment – the Yellow River. A non-linear programming model, the Yellow River Basin Model, was used to simulate conditions in the Yellow River with and without the WWTP abstraction in place. The model included the storages provided by the Wanjiazhai Dam, under construction at the time, as well as another new large dam some 400 km downstream, the Xiaolangdi Dam, also under construction. The impact of the WWTP on users downstream in the Yellow River, as well as the environmental needs of the estuary, was assessed and found to be minimal. Contributing reasons were that the abstraction was small relative to the MAR of the Yellow River as well as that some 60% of the water diverted by the WWTP was considered to find its way back to the Yellow River through return flows (World Bank, 1997:244-249).

Low, medium and high scenarios of growth in water demands were analysed in the SAR (World Bank, 1997:55). The “medium” scenario was accepted as the most likely and used in further analysis. Accordingly the projected total M&I demand, and envisaged shortages, taking into regard the sustainable water availability, were determined as summarised in Table 5-9 (1997:165)

Table 5-9: Projected water demands and shortages in Taiyuan

Year	M&I Demand (million m^3/year)	Shortage (million m^3/year)
2000	481	209
2002	535	263
2005	628	356
2010	825	553
2015	982	710
2020	1170	898

5.9.2.2 Water transfers

The SAR envisaged that water transfers from the Yellow River would begin at the level of 269 million m^3/a in 2002, when the project was envisaged to deliver first water and, according to the base case scenario, water transfers were to grow steadily from that level until it reached full delivery capacity of 640 million m^3/a by the year 2011, after which water would be transferred constantly at the latter capped rate (World Bank, 1997:186).

5.9.2.3 Appraisal approach

A full CBA was conducted as part of the appraisal by the World Bank. The benefits comprised (a) benefits from increased human consumption, assessed from consumer surplus estimates, (b) increased industrial production due to water shortages being eliminated and (c) increased irrigation farming production utilising the effluent water from the project (after appropriate treatment) (World Bank, 1997:55-58).

The costs component was divided into Project Costs, i.e. costs incurred during the implementation of the project (main works, water treatment and supply networks for Taiyuan City) and recurrent costs, being incremental operation and management costs. From the benefit and cost streams, using a 50 year project life and a 12% discount rate, an economic internal rate of return (EIRR) of 22%, and a benefit-cost ratio of 1.7, was derived (World Bank, 1997:59).

Included in the cost stream were variable costs, i.e. costs that were directly related to the quantities of water transferred. These comprised electricity costs for the pumping of the water and costs for treating the Yellow River water, as desilting and additional treatment was required to render the water utilisable. From the information presented in the SAR (see ANNEXURE 5-I) it is deduced that these variable costs (i.e. costs directly related to the water quantities transferred) constituted almost half of the estimated 14 783 million Yuan (1996 prices) discounted present value economic cost of the project (World Bank, 1997:186).

Partial sensitivity analyses were also conducted by sequentially changing input parameters in the CBA, such as using a low growth scenario or increasing operational costs. These analyses confirmed the positive appraisal of the project.

5.9.3 Post implementation investigation

The first phase of the WTTP was completed in 2005 and the results evaluated in a follow-up ICR report (World Bank, 2007).

The ICR noted that the actual growth in water demand fell far short of the projections in the SAR, thereby reducing the need for transfers of water from the Yellow River. The ICR ascribed it largely as a failure in the SAR to appreciate the extent and pace at which water-saving technologies would be adopted by industries in the area (World Bank, 2007:3). A number of factors contributed to the rapid change, not least the pricing structure enforced; the price of ground-water was only 40% of that of the surface water resource. While the economy kept growing at 6.6% p.a. between 1993 and 2002, water demand fell by 11.4% p.a. The ICR found that the utilisation of the installed capacity of the WWTP (which was half of the design capacity) was only 23% (World Bank, 2007:22).

The fact that the WWTP did not reach the transfer volumes envisaged in the SAR caused the ICR to state that a “physical target/year of the volume of water transferred from the Yellow River” should have been provided as part of the Monitoring and Evaluation design in the SAR (World Bank, 2007:8).

5.9.4 Discussion and evaluation

The SAR assumed that the required annual water transfer for each year in the future would be exactly equal to the deficit projected, the latter being the difference between the projected water demand and the sustainable yield of the local water resources. The SAR did not consider that there would be a likelihood of periods in future years that the receiving basin would have excess local yield available and that the required transfer quantities, therefore, could be lower. The modelling of the source catchment, the Yellow River, was done independently from the modelling of the receiving catchment.

It would have been interesting to see what the hydrological conditions in the receiving basin were since the completion of the project and to compare that against the actual water transfers that had taken place since the completion of the WWTP. Unfortunately, despite several attempts, such information was not made available. However, a hydrograph over a twenty year period at the Hejin station near the confluence of the Fen River with the Yellow River is presented in Figure 5-14 (Australian Bureau of Meteorology, s.a.). From this graph can be deduced that the characteristics, especially regarding variability, of the Fen River are very similar to those of the rivers in South Africa, e.g. as depicted in Figure 5-15 for the Vaal River at Vaal Dam, with its relatively high coefficient of variation (CV) of 0.78 (Nel, 2012).

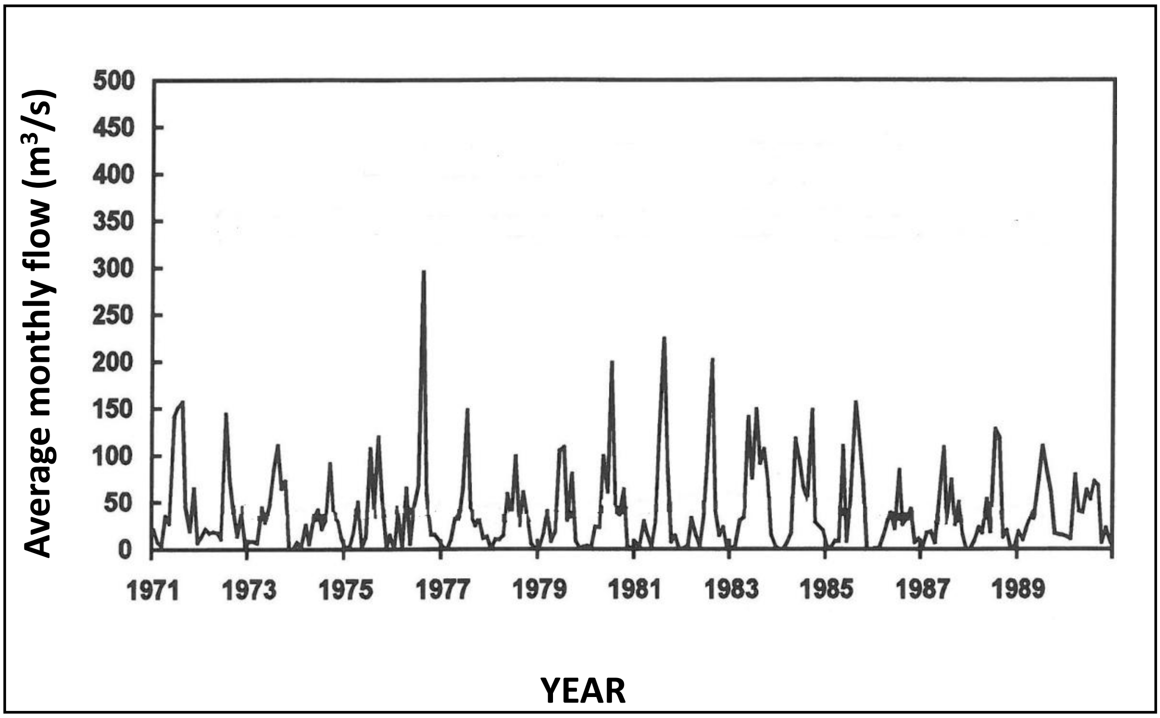

Figure 5-14: Stream-flow hydrology of the Fen River at Hejin

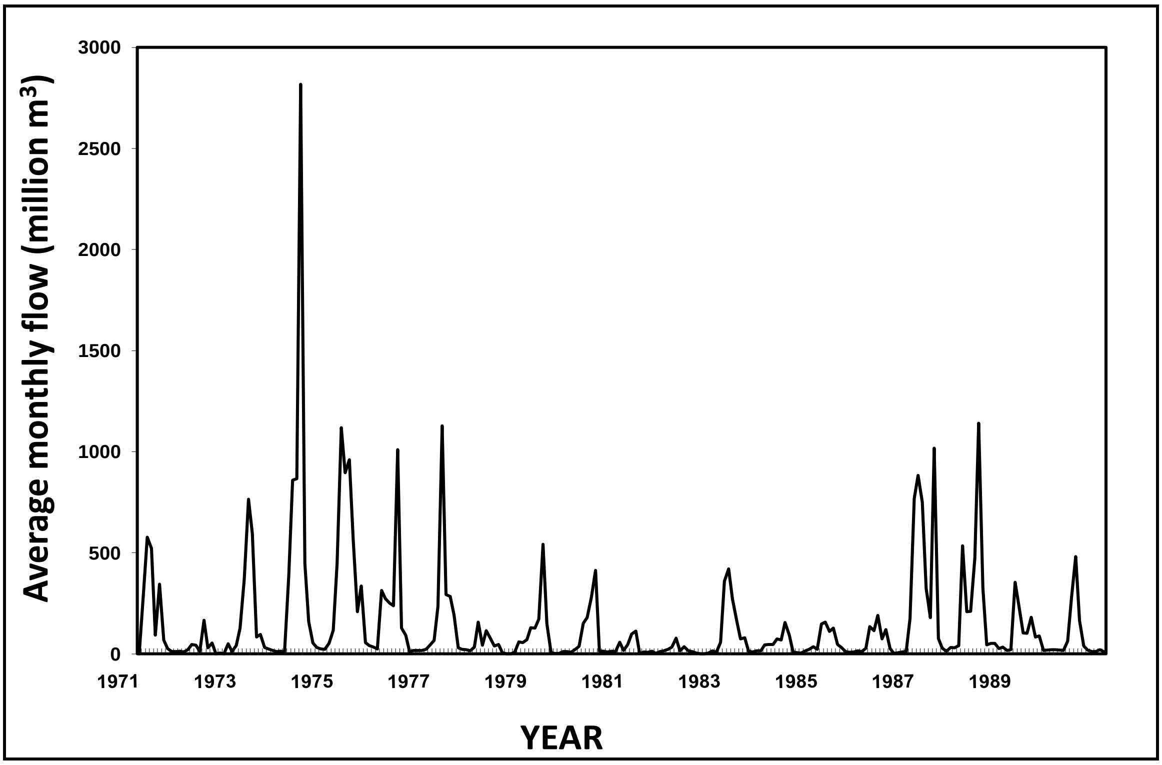

Figure 5-15: Vaal River hydrology (naturalised) at Vaal Dam

As for the Vaal River, there would be periods that the receiving basin of the WWTP (i.e. the upper Fen) has conditions of excess yield. It is therefore quite reasonable that more water than the limit of the “sustainable yield” of the local resource, as set in the SAR, could be abstracted during such periods. The real-time model that predicted conditions seven days in advance automatically would have made adjustments to the required transfers based on the conditions in the receiving catchment.

The ICR pointed to the reduction in water demand as the reason for the under utilisation of the WWTP. This probably was the main reason, but the ICR did not consider the possibility that a contributory factor to the reduced transfers could be due to variable hydrological conditions in the receiving basin.

On the basis of the envisaged transfers, future variable costs of the scheme were calculated. This probably led to an overestimation of this cost component (as demonstrated), which would have affected the CBA assessments.

The actual growth in water requirements in the Taiyuan area was markedly reduced due to improved efficiencies of water use. This phenomenon lowered the need for water transfers and thus probably masked the expected lowering that could have been foreseen from an integrated systems context.

In conclusion: the appraisal approach followed in International Case Study 4 is evaluated against the criteria set in paragraph 5.3:

a) Neither of the two World Bank assessments, the SAR and the ICR, considered the need for an integrated hydrological assessment of the source and receiving basin, jointly, in a total systems context. No simulation of annual operations, and likely water quantities to be transferred, was performed
b) The assumption was made in both World Bank assessments, the SAR and the ICR, that the Wanjiazhai Water Transfer Project would be required to provide all incremental water beyond the yield capability of the existing system.

It is thus concluded that the approach used in this case study was completely analogous to that of the Incremental Approach described in Chapter 1.

5.10 International Case Study 2: Water augmentation to South East Queensland, Australia

This case study examines the appraisal process applied during the investigation into the options to augment the water resources of South East Queensland.

5.10.1 Background

South East Queensland (SEQ) in Australia experienced its worst drought on record in the first decade of this century. The average rainfall at Wivenhoe Dam (see Figure 5-16 for locality), the main storage dam for the city of Brisbane with its 2 million inhabitants, was only 634 mm/a for the period 2001-2009 compared to the average of 1069 mm/a for the preceding 52 years (Queensland Water Commission, 2010:32). Severe water restrictions were imposed on this fast growing region and the drought prompted the Department of Natural Resources and Water of the Government of Queensland to undertake a comprehensive investigation into options to augment the water resources of the affected area (Wasimi 2011:26). This resulted in a report entitled *Water for South East Queensland – a Long Term Solution*[10] (Queensland Government, 2006).

The *Long Term Solution* report identified a wide-ranging set of measures to deal with the immediate shortages as well as the long term security of water supplies of the region. In addition to demand management measures, project development scenarios (called “supply portfolios”) were investigated to meet envisaged demands fifty years into the future, i.e. from 2007 to 2056. A number of sites were identified for possible dams to augment the existing Wivenhoe-Somerset Dam system that supplies Brisbane and surrounding areas with water (see Figure 5-16). Some of these schemes involve IBTs and significant pumping.

[10] Henceforth referred to as the *Long Term Solution* report.

Figure 5-16: SEQ: Locality of the existing and envisaged water infrastructure. (Queensland Water Infrastructure, 2007:1-3)

The Traveston Crossing Dam featured in all of the identified scenarios as the next major storage dam of the SEQ region. The most attractive scenario was found to be the Traveston

Crossing Dam on the Mary River to the north of Brisbane followed by a dam to the south at Wyaralong on the Teviot Brook, a tributary of the Logan River. This scenario was therefore recommended for implementation in the *Long Term Solution* report.

To deal with the immediate crisis the Queensland Government decided to embark on a sea-water desalination plant to the south of Brisbane at Tugun, an effluent re-use project to supply recycled water to power stations (the Western Corridor Recycled Water Project), and a small off-channel storage dam on the Logan River, called the Bromelton Off-stream Storage scheme. It was also decided that the Traveston and Wyaralong Dams should be targeted for completion in 2012 (Marsden Jacob Associates, 2007a:8).

To implement the plan the Queensland Water Commission was established through an Act of Parliament on 17 May 2006 (Queensland Government, 2006:80-81). In addition a government company, Queensland Water Infrastructure (Pty) Ltd, was established to undertake the construction of the Wyaralong and Traveston dams.

The proposal to build the Traveston Crossing Dam was met with stiff opposition from the communities in the Mary River valley as well as from environmentalists (Wasimi 2011:26). Queensland Water Infrastructure (Pty) Ltd accordingly embarked on an environmental impact assessment of the Traveston Dam project, which included appraisals of alternative surface water developments as well as rainwater harvesting, seawater desalination, water recycling and demand management to balance water demands with supplies (Queensland Water Infrastructure, 2007:1-5 to 1-13).

A number of alternative development scenarios, described in paragraph 5.10.3.2, were investigated.

5.10.2 Summary of investigations

This section summarises the investigations and their findings.

5.10.2.1 Water requirements

The *Long Term Solution* report provided for three water demand scenarios: “business as usual”, “adopted demand” (which indicated moderate savings) and “high savings” (see Figure 5-17). The moderate savings scenario, which projected a total water requirement of 750 million m^3/a or 300 million m^3/a of additional supply requirement by 2050, was used for the purposes of further planning (Queensland Government, 2006:24).

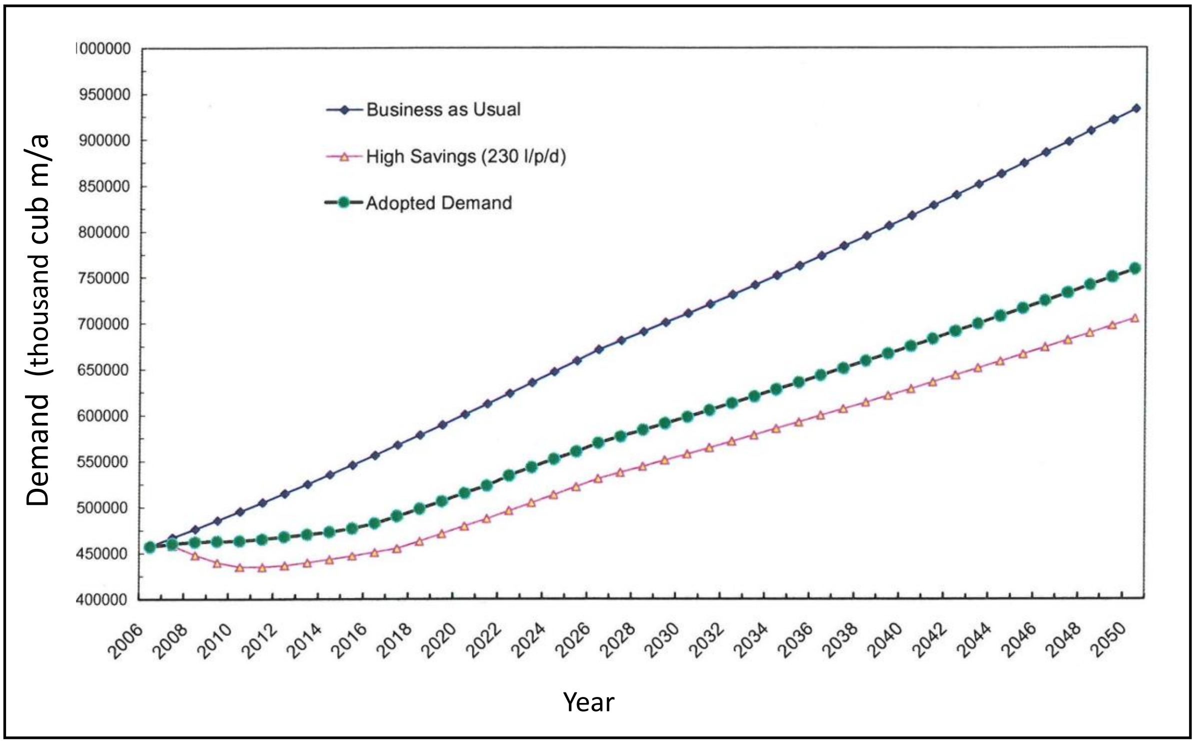

Figure 5-17: SEQ Projected Water Demands. (Source: Queensland Government, 2006)

The "adopted demand" depicted in Figure 5-17 was also used in subsequent economic analyses (Marsden Jacobs Associates, 2007a:6-13).

5.10.3 Available water resources

The Wivenhoe-Somerset Dam system, together with the Hinze Dam, the North Pine Dam and the Baroon Pocket Dam, provided for over 80% total supply of the SEQ region. More than half of the urban water supply was sourced from the Wivenhoe-Somerset Dam system (Turner et al., 2007:15).

The *Long Term Solution* report (Queensland Government, 2006:43-50) estimated the "historic no failure yield" (equivalent to HFY) of the Wivenhoe-Somerset Dam system at 373 million m^3/a. A stochastic analysis was undertaken of the system and it was concluded the 1 in 50 year (i.e. 98% probability) yield of the system was only 285 million m^3/a, and the 1 in 100 year yield 260 million m^3/a. It was recommended that the 1 in 50 year level of assurance should be adopted and the ratio between this yield and the HFY be used to "de-rate" the yields of the other dams so as to obtain the "prudent yield" of the combined resources, estimated at 450 million m^3/a. (Note that an error was made in the calculations of the 1 in 50 and 1 in 100 year system yields of the Wivenhoe-Somerset Dam system causing these to be underestimated. This is described in ANNEXURE 5-J.)

5.10.3.1 Envisaged shortfalls

From the projections and the assessment of the available resources the projected future shortfalls were identified, as summarised in Table 5-10 (Queensland Government, 2006:50).

Table 5-10: Projected SEQ water supply shortfalls

	Year			
	2026		2050	
Scenario	"Business as usual"	"Medium Savings"	"Business as usual"	"Medium Savings"
Anticipated Demand (million m^3/a)	670	570	950	750
Existing "prudent yield" (million m^3/a)	450	450	450	450
Shortfall (million m^3/a)	220	120	500	300

5.10.3.2 Options to meet anticipated shortfalls

Five development scenarios were analysed. Yields were determined individually for each element in the scenarios, but it was recognised that, when operated as a system, certain advantages would be gained due to envisaged low correlations between the resources. No systems analyses were undertaken for the various scenarios, but it was envisaged that modelling would happen in due course, providing improved yield estimates (Marsden Jacobs Associates, 2007b:13).

The first scenario, called the base-case, is illustrated in Figure 5-18. It comprised the Traveston Crossing and the Wyaralong Dams, followed by the raising of the existing Borumba Dam, a new Glendower Dam on the Albert River – a tributary of the Logan River – a raising of the Traveston Crossing Dam and then the desalination of sea-water.

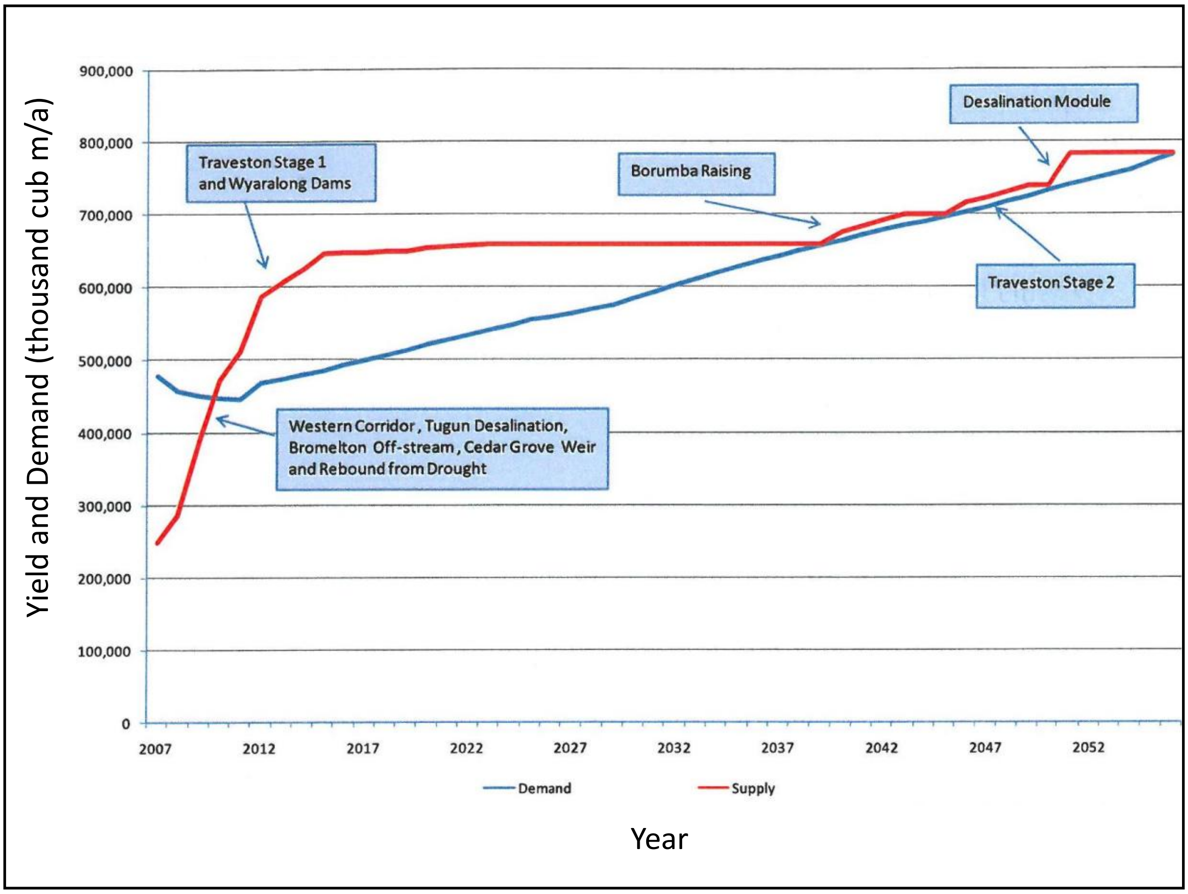

Figure 5-18: SEQ projected yield vs. demand projection – base-case

Four alternative development scenarios to the base-case scenario were examined by Marsden Jacobs Associates (2007a:13-18). These were:

a) A desalination portfolio (shown in Figure 5-19) where all water is supplied from new sea water desalination plants north of Brisbane
b) A Mary River smaller dam portfolio (shown in Figure 5-20) consisting of four new small dams and the raising of a fifth, followed by desalination
c) A New South Wales (NSW) northern dam alternative (shown in Figure 5-21) consisting of a large dam, comparable to the Traveston Crossing Dam, on the Clarence River, followed by the Wyaralong Dam and desalination afterwards
d) A smaller dam portfolio (shown in Figure 5-22) comprising the Wyaralong, Glendower and Amamoor dams, and the raising of the Borumba dam, followed by desalination.

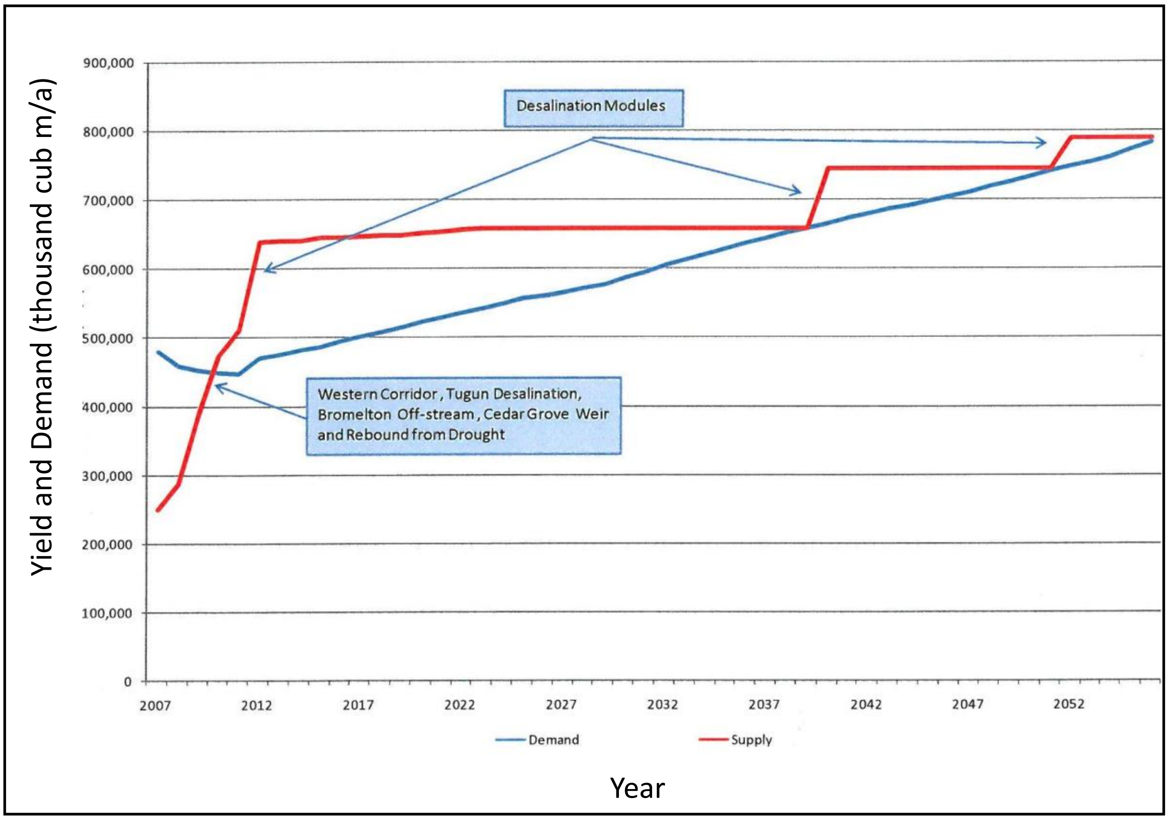

Figure 5-19: SEQ: Desalination only – Alternative 1

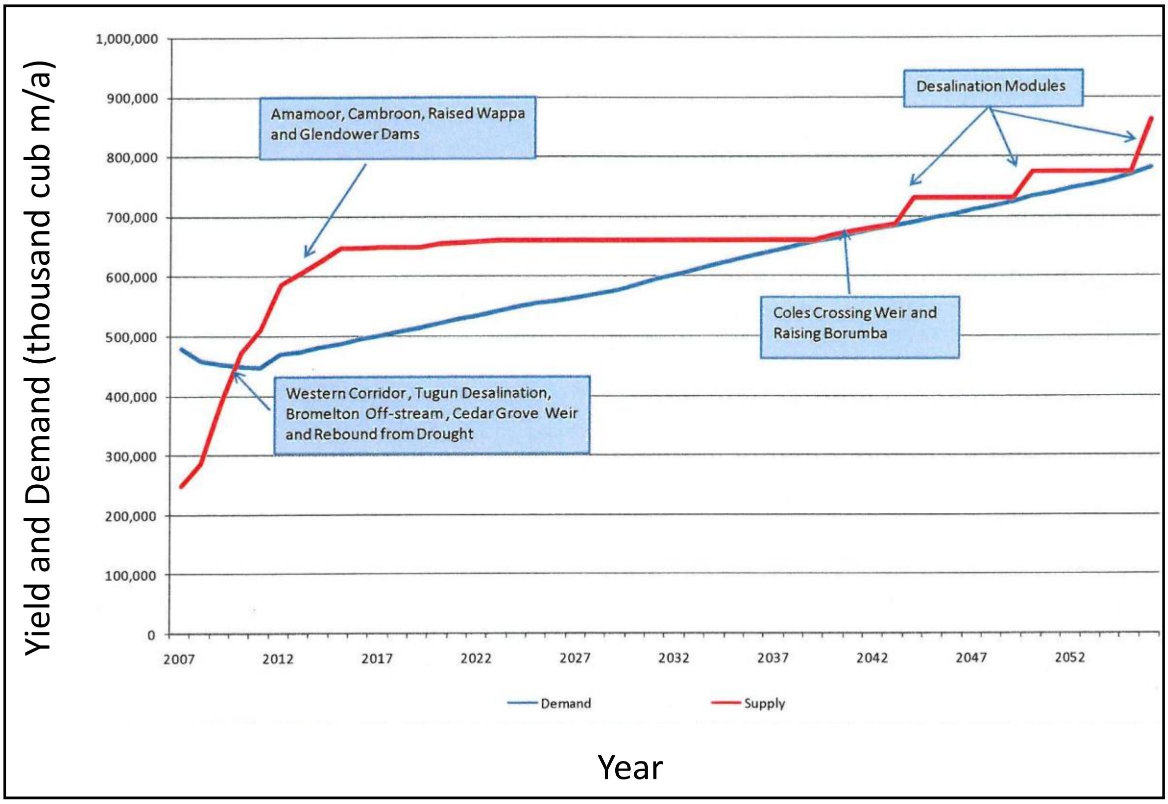

Figure 5-20: SEQ: Smaller dams on the Mary River – Alternative 2

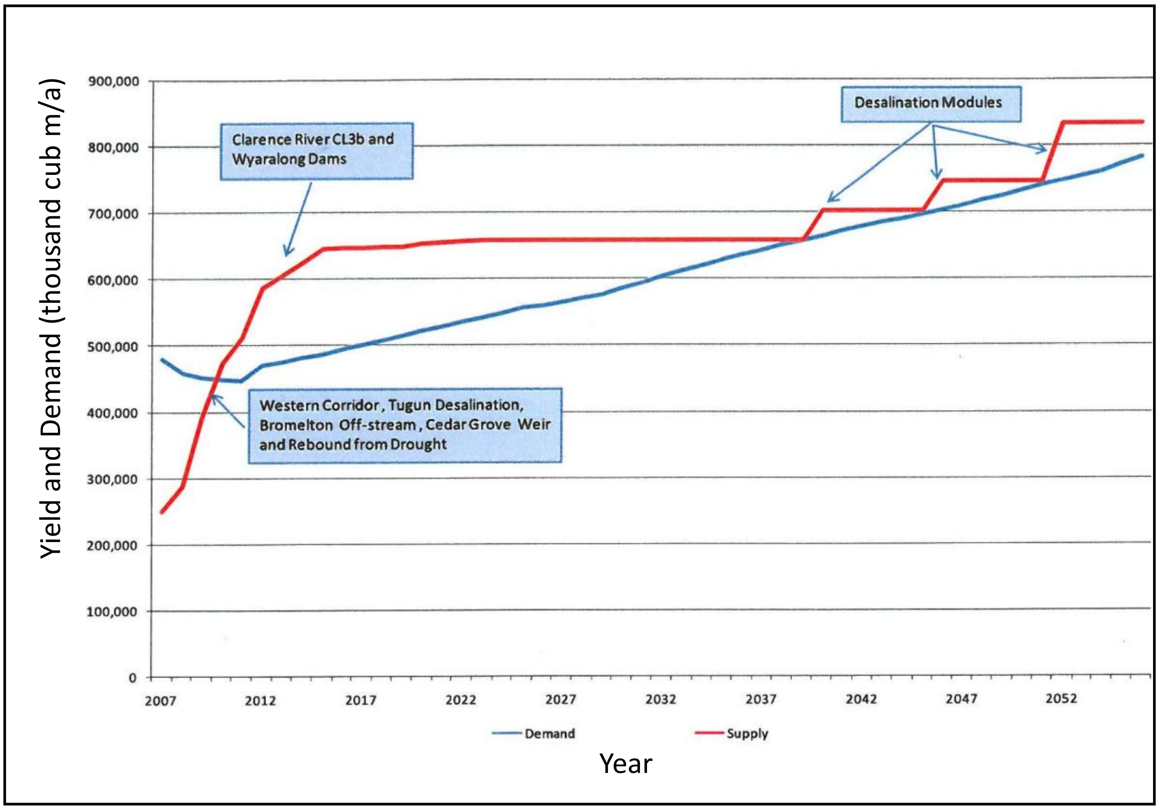

Figure 5-21: SEQ: Augmentation from Clarence River in New South Wales – Alternative 3

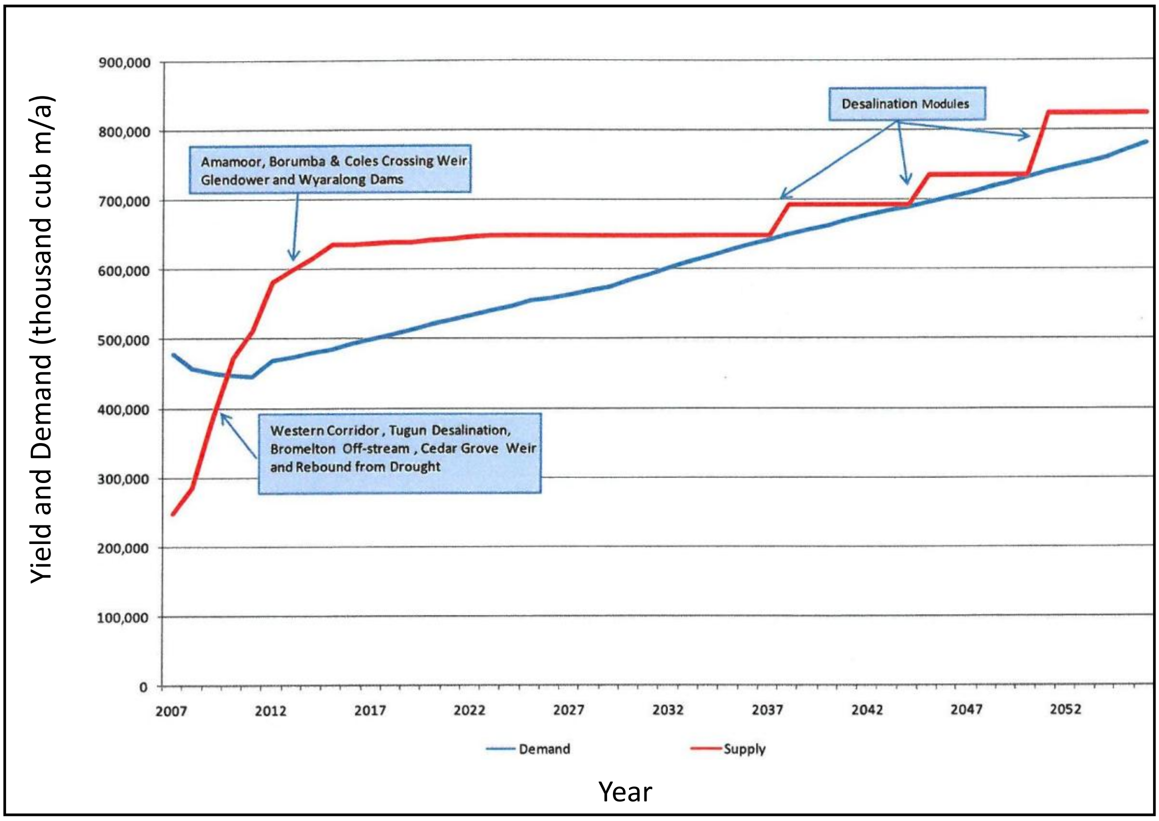

Figure 5-22: SEQ: Development of smaller dams – Alternative 4

5.10.3.3 Costing

The elements of the above scenarios were individually costed. ANNEXURE 5-K provides a breakdown of these costs. A distinction is made between “Source: variable costs”, “Connection: variable costs” and “Treatment: variable costs”. The “Source: variable costs” applied only to the desalination options. The “Connection: variable costs” referred to the cost of transferring the untreated water, and the “Treatment: variable costs” to the purification as well as the conveyance of the treated water (Marsden Jacobs Associates, 2007a:45).

Marsden Jacobs Associates noted that the operating costs in ANNEXURE 5-K assumed supply at full capacity over the full 50 year period of analysis. They noted that that was not a reasonable assumption as there would be periods of surplus capacity due to the indivisibility, or “lumpiness”, of water resource capacity expansion projects. In their economic evaluation of the portfolios they therefore selected supply from the projects with lowest variable costs available during the periods that the capacity exceeded the growth curve and calculated variable cost according to the level of actual volume assumed to be supplied from such projects. They stated that this was “a reasonable approach given that operating rules have not been developed...” (Marsden Jacobs Associates, 2007a:23) but also that it had “a small bearing on the overall operating costs for each supply portfolio modelled“ (2007a:20).

5.10.3.4 Economic analysis

The principal purpose of the economic evaluation of stage 1 of the Traveston Dam was to test whether the proposed plan of the Queensland government, i.e. the base-case scenario, was economically the most efficient one (Marsden Jacobs Associates, 2007a:1). The report stressed the efforts undertaken to ensure that the evaluation was robust. Numerous workshops were held to fill data gaps and separate reviews were done which led the authors to conclude that the Traveston Dam was “the only major water supply infrastructure development in Australia where such a rigorous process has been applied to facilitate transparent and rigorous comparison of the economic cost of a wide range of water supply options. Thus, there is a very high degree of confidence in the results of the economic modelling” (2007a:3-5).

Present value assessments by means of spreadsheet modelling of each of the portfolios were made. A discount rate of 4% was applied for a 50 year period of analysis for each portfolio. Capacity expansion was timed to occur when the demand reached the available supply capacity, and the variable costs minimised in years of surplus capacity. The results of the assessments are shown in Table 5-11 (Marsden Jacobs Associates, 2007a:26).

Table 5-11: Present value comparison of alternative portfolios to Traveston Crossing Dam (TCD) (2007 Aus$)

Scenario	Base case	1	2	3	4
	Traveston Crossing Dam	Desalination	Mary River Dams	NSW Northern Dam	Smaller Dams
Capital Cost	7 364	7 173	8 087	7 684	7 898
Fixed operating costs	1 589	1 887	1 827	1 747	1 963
Variable operating costs	737	949	817	910	839
Total	9 690	10 008	10731	10 341	10 700

The Traveston Crossing Dam portfolio was found to be economically the most efficient. Marsden Jacobs Associates undertook a number of sensitivity analyses to test the robustness of their findings and concluded that "the results are clear and unambiguous that based on the cost and hydrological data provided to Marsden Jacobs the TCD Portfolio represents the least cost surface water supply option under all scenarios examined" (Marsden Jacobs Associates, 2007a:38).

5.10.3.5 Discussion and evaluation

It was shown that the water supply system of the fast-growing SEQ region is complex; by 2006 there were a number of storage dams serving the area through an intricate interlinked water supply system.

The investigations undertaken to meet the projected requirements of the future, first by the Queensland Government and thereafter by the Queensland Water Commission and the Queensland Water Infrastructure (Pty) Ltd, were thorough except in respect of the (all-important) hydrological component that laid the foundation for their work. In the earlier planning no comprehensive systems analyses were undertaken of the supply systems, as they existed at the time or as were projected to expand into the future. Apart from the stochastic assessment of the yield of the Wivenhoe-Somerset system, yields were simply added together to obtain an overall "system" yield.

As the actual spreadsheets of the modelling undertaken by the economists Marsden Jacobs Associates were not included in their reports, inferences are required from the descriptions provided as to how variable costs were determined. While they mentioned that sources with lowest variable costs were targeted when surplus capacity situations were projected, it is clear, from these descriptions, that the assumption was made that all requirements beyond existing yield capability were required to be provided from the new resources postulated. There was no recognition of a likelihood in the future that surplus conditions could occur in the existing system and therefore that the transfers from the more expensive schemes during such periods could be reduced.

In conclusion: the appraisal approach followed in International Case Study 2 is evaluated against the criteria of paragraph 5.3 as follows:

a) A full system analysis with the inclusion of the receiving basin as well as the proposed IBT projects was not undertaken. No simulation of annual operations and likely water quantities to be transferred was accordingly performed
b) The assumption was made that all incremental demand, beyond the yield capability of the existing system, had to be supplied from the new resources.

It is thus concluded that the approach used in this case study was completely analogous to that of the Incremental Approach described in Chapter 1.

5.10.4 Postscript regarding SEQ water resource planning

In 2010, after the drought broke in 2009, the Queensland Water Commission issued the updated *South East Queensland Strategy* (Queensland Water Commission, 2010). The strategy completely revised the *2006 Long Term Solution* report; demands were reassessed, greater emphasis was placed on demand management measures and climate change was considered. It also took into account the cancellation of the Traveston Crossing Dam (2010:15) and avoided the initial very large over-supply situation.

For the *South East Queensland Strategy*, modelling was undertaken to establish the yield of the, so called, SEQ Water Grid as a whole, using synthetically generated data sets. The one in 25 year yield of the system with the inclusion of the Wyaralong Dam was assessed at 525 million m3/a. (Note that the one in 25 year yield became the level-of-service standard for this strategy.) The system analysis methodology was an improvement on the previous method of estimation of the "system yield of a suite of integrated sources of supply ... based on an aggregation of yields of individual sources of supply, treated as unconnected" (Queensland Water Commission, 2010:43). Also it was found that "modelling of the regional water balance in two different modes – connected and disconnected – has determined that, if the sources of supply existing in 2006 were operated as a connected SEQ Water Grid, there would have been an estimated increase in the system yield of about 14 per cent" (Queensland Water Commission, 2010:87).

The *South East Queensland Strategy* also described the SEQ System Operating Plan which would regularly be reviewed taking cognisance of the need to strike a balance between supplying water with maximum security and minimising costs. It was stated that the SEQ System Operating Plan "will allow for the take of water from specific sources to vary over time depending on a range of factors, including inflows to dams, operating costs and risk management" (Queensland Water Commission, 2010:83).

While the SEQ System Operating Plan envisaged balancing costs of operation with risk of water shortages, similar to the Annual Operating Analyses undertaken by the DWA in South Africa (see paragraph 4.3.2), the expected variable costs were not *a priori* included in the selection process to optimise capacity expansion. There is therefore no indication that there was a move away from the Incremental Approach at the planning appraisal stage.

5.11 Conclusions regarding the current use of the Incremental Approach in the RSA and internationally

Six case studies were reviewed in this chapter: four from South Africa, one from China and one from Australia. All six cases covered investigations that were undertaken into possible IBT projects – to establish their viability. The investigations were undertaken by a range of consultancies and agencies, respected in the field of water resource engineering and management.

In all six case studies it was found that (a) the increase in system yield was derived from an analysis of the source system separately from the receiving system, and (b) the estimates of water to be transferred by the IBTs were assumed equal to the predicted shortfalls in the receiving system – shortfalls that were derived by subtracting from the demand predictions the system, as it existed, yields. The predicted transfers therefore all exhibited patterns of smooth growth, until the point of being capped by the yield capability of the IBT after which the predicted transfers remained constant.

As variable transfers costs were directly related to the volumes of water transferred, these costs exhibited a similar pattern.

From these findings it is concluded that:

a) The practice generally followed in South Africa is still analogous to the approach followed in the early years when the Usutu-Vaal and Tugela-Vaal Government Schemes were planned, described as the Incremental Approach in paragraph 1.1.1.
b) The two international case studies indicate that the appraisal approach followed is basically similar to the approach in South Africa.

The quality of the design of the case study research in this chapter can by tested according to the criteria described by Yin (2009:40-43). *Construct validity* was assured by the choice and applicability of the case studies, as motivated in paragraph 5.2, while *reliability* was catered for by the repeatability of the findings. *External validity was* found in the evidence that the findings could be generalised in the domain of appraisal of IBTs in South Africa, in particular, with a strong likelihood that the findings are also extendable to the international domain.

It is thus concluded that sub-hypothesis 2, that *the Incremental Approach is generally being applied in the appraisal of IBT projects*, is supported.

6 Towards a Comprehensive Approach

The case study research reported on in previous chapters showed that the Incremental Approach of project appraisal does not adequately describe, in the case of IBT projects, future water transfers, and their associated variable costs. In this chapter the Incremental Approach (IA) is adapted and improved to deal with these shortcomings, leading to the proposed Comprehensive Approach resulting from this research.

6.1 Purpose

The need for an integrated analysis of a water resource system when undertaking the planning appraisal of a proposed inter-basin transfer (IBT) project was demonstrated in Chapter 3. The Incremental Approach of appraisal, and therefore decision-making, of IBT projects does not make provision for the demonstrated uncertainty of future water transfers. In this regard the IA follows a deterministic path which requires expansion – by including stochastic inputs.

6.2 Obtaining a probabilistic perspective of likely water transfers

In this section the case of the possible Thukela Water Project (TWP), reported on in the RSA Case Study 4 in the previous chapter in paragraph 5.8, is used as an example to demonstrate the application of existing modelling techniques to obtain a probabilistic perspective of likely future water transfers.

Paragraph 5.8.1 referred to the *Comparative Study, a* recent study by the DWA to compare the TWP with the second phase of the Lesotho Highlands Water Project (LHWP II) (DWA, 2010e). In that study a comparison was made between constructing a dam at Polihali in Lesotho, with a connecting tunnel to the existing Katse Dam and, alternatively, the construction of the TWP, comprising the Jana Dam on the Thukela. followed by the Mielietuin Dam on the Bushman’s River, pumping stations and aqueducts to transfer the water to Sterkfontein Dam as an extension of the existing Tugela-Vaal GWS, as illustrated in Figure 6-1 (DWA, 2010e:81).

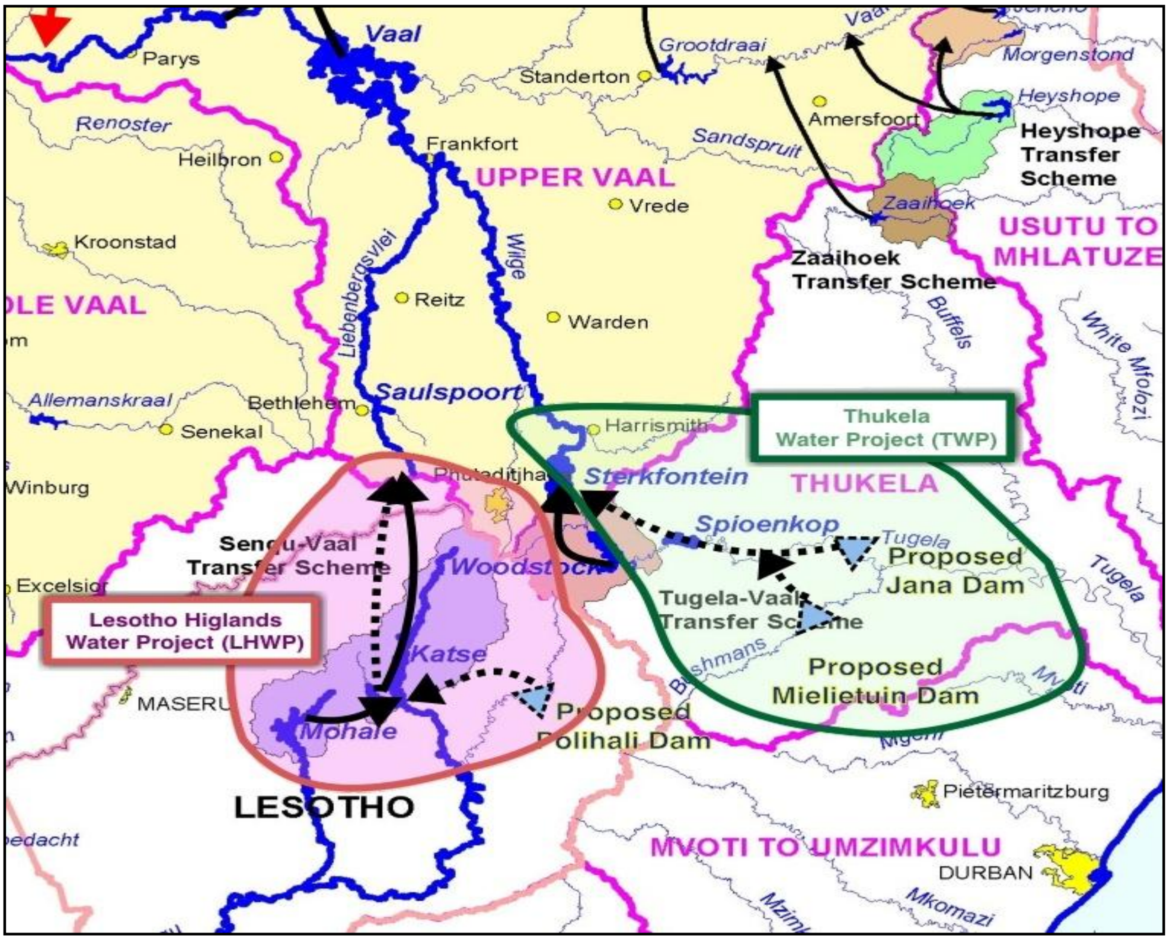

Figure 6-1: Map of LHWP with Polihali Dam (Phase II) and the TWP as alternative

A number of scenarios of growth of demand in the Vaal River, with and without water demand management and re-use of mine water and urban effluent, were investigated. With the aid of the WRPM (described in paragraph 2.2.3), water transfers from the proposed Polihali Dam in Lesotho, with optimal operation and the transfer capacity limited by the tunnel capacity of 465 million m^3/a, or 14.74 m^3/s, were simulated for the E2 water requirement scenario.

The E2 scenario assumed a high population growth, a 15% demand reduction through demand management measures, the desalination and re-use of mine water discharges, and support to a new oil-from-coal facility in the Waterberg coal fields near Lephalale (DWA, 2010e:22).

A total of 995 stochastic runs of 41 years length, starting in 2010 and ending in 2050, were simulated. The actual water transfers simulated in each run for each month of the 41 years were recorded (this required a specific setting *a priori* before simulating). In this way 995 stochastic water transfer records, each of 41 years length, were synthetically generated, simulating the transfers that would have been required under operational conditions with the starting conditions and the water requirements pertaining to each year for each sequence (Van Rooyen, 2012).

Due to the bulkiness of the complete record, only an extract of the data, viz. that of run sequences one to five, is provided in Table 6-1. Note that the Polihali Dam will only be able to deliver water from 2020 onwards.

Table 6-1: First five of 995 stochastic sequences of 41 year transfers generated for the Second Phase of the LHWP

Year	Year sequence	Sequence 1 flows (million cub m/a)	Sequence 2 flows (million cub m/a)	Sequence 3 flows (million cub m/a)	Sequence 4 flows (million cub m/a)	Sequence 5 flows (million cub m/a)
2010	1	0.0	0.0	0.0	0.0	0.0
2011	2	0.0	0.0	0.0	0.0	0.0
2012	3	0.0	0.0	0.0	0.0	0.0
2013	4	0.0	0.0	0.0	0.0	0.0
2014	5	0.0	0.0	0.0	0.0	0.0
2015	6	0.0	0.0	0.0	0.0	0.0
2016	7	0.0	0.0	0.0	0.0	0.0
2017	8	0.0	0.0	0.0	0.0	0.0
2018	9	0.0	0.0	0.0	0.0	0.0
2019	10	0.0	0.0	0.0	0.0	0.0
2020	11	0.0	0.0	41.2	0.0	0.0
2021	12	0.0	0.0	0.0	0.0	0.0
2022	13	0.0	0.0	0.0	0.0	0.0
2023	14	0.0	0.0	0.0	0.0	0.0
2024	15	0.0	0.0	0.0	0.0	118.2
2025	16	0.0	0.0	0.0	0.0	0.0
2026	17	0.0	0.0	0.0	0.0	0.0
2027	18	0.0	0.0	0.0	0.0	0.0
2028	19	0.0	0.0	0.0	0.0	0.0
2029	20	152.6	0.0	256.4	0.0	0.0
2030	21	465.0	0.0	0.0	226.5	0.0
2031	22	0.0	0.0	0.0	0.0	0.0
2032	23	35.0	64.7	0.0	0.0	0.0
2033	24	0.0	0.0	0.0	0.0	0.0
2034	25	0.0	0.0	0.0	15.0	0.0
2035	26	143.3	0.0	0.0	396.7	0.0
2036	27	0.0	0.0	0.0	40.5	233.8

Year	Year sequence	Sequence 1 flows (million cub m/a)	Sequence 2 flows (million cub m/a)	Sequence 3 flows (million cub m/a)	Sequence 4 flows (million cub m/a)	Sequence 5 flows (million cub m/a)
2037	28	0.0	13.5	48.6	0.0	465.0
2038	29	0.0	0.0	39.5	0.0	465.0
2039	30	0.0	61.1	465.0	0.0	0.0
2040	31	0.0	162.1	465.0	221.5	0.0
2041	32	0.0	0.0	0.0	0.0	0.0
2042	33	163.0	0.0	0.0	0.0	0.0
2043	34	0.0	0.0	0.0	0.0	0.0
2044	35	0.0	0.0	0.0	412.9	0.0
2045	36	0.0	0.0	0.0	157.3	435.7
2046	37	282.5	0.0	20.3	373.6	465.0
2047	38	465.0	207.5	124.1	165.4	0.0
2048	39	441.4	0.0	218.6	0.0	28.2
2049	40	401.0	167.6	171.8	18.5	108.7
2050	41	268.4	463.4	101.3	31.7	87.5
Notes:	First delivery of water from LHWP II in 2020					
Present value (2010) of water transfer @ 8% p.a.		256.5	72.2	202.5	196.8	234.7

In analysing the operational regime for the Polihali Dam it became evident that it would be optimal for the water to be kept in storage as long as possible before it is released downstream. The reasons for this are that (a) the evaporation losses in the Polihali Dam will be far less, and therefore the storage more efficient, than that of the dams lower in the system, e.g. the Vaal Dam, and (b) keeping in storage the water in the upper parts of the system creates more opportunities for capturing floods generated in the catchments of the entire system.

In the case of the TWP, water will similarly be kept back in the Thukela Basin for as long as possible to avoid pumping costs. As the storages and conveyance structures are comparable in size, and as both alternatives are intended to serve the same users over the same time-frame, it is reasonable to assume that the transfer characteristics of the two schemes will be similar and thus, for purposes of demonstrating the application of the Comprehensive Approach later in par. 6.7, that the 995 stochastic transfer sequences derived for Polihali Dam be considered equally applicable to the TWP (Van Rooyen, 2012).

6.3 Validation of modelling of water transfers

The five sequences extracted in Table 6-1 have been graphically depicted in Figure 6-2. Visually no clear pattern emerges except that the graphs can be typified as being of an erratic nature, bounded by zero and the maximum transfer capacity of 465 million m^3/a.

The graphical depictions of the modelled sequences of water transfers in Figure 6-2 can be compared with the observed patterns reported for water actually transferred to the Little Vaal River from the Usutu Basin by means of the Usutu-Vaal River GWS (Second Phase) (see Figure 4-3), and the historic transfer volumes from the Slang River to the Skulpspruit by means of the Slang River GWS (see Figure 4-5). Visually these records exhibit similar characteristics, being erratic and unpredictable, both in the quantum, i.e. the size of transfer, as well as time, i.e. year to be expected. This creates confidence that the modelled transfers are similar in character to what can be expected in reality.

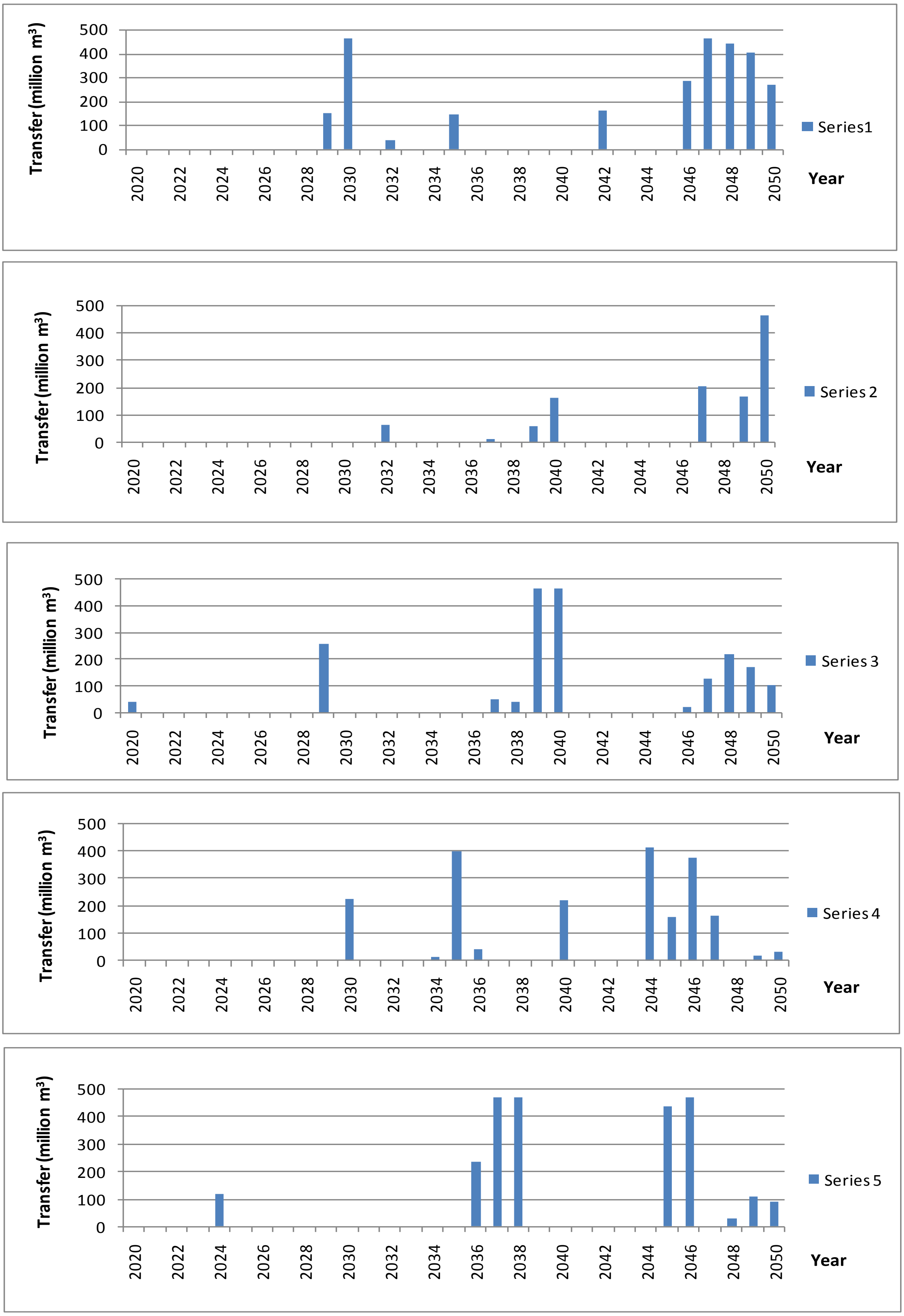

Figure 6-2: Graphical depiction of first five of 995 transfer sequences generated for the Second Phase of the LHWP

6.4 Stochastic water transfers and variable costs

This section demonstrates the derivation of the appropriate input cost for appraisal of an IBT project by using the stochastic water transfer data obtained in paragraph 6.2.

6.4.1 PV of water transfers

The Incremental Approach used water transfers as input in the determination of both the operating costs as well as the derivation of the URV (see paragraph 1.1.1). The first important step is to separate the application of the water transfers as denominator of the URV from that as input for the operating costs. It is the latter that is addressed first.

In the example in this chapter the 995 stochastic sequences of water transfer can be used as input into the appraisal model. The PV of the water is now determined for an appropriate annual discount rate. As discussed in paragraph 2.3 a social discount rate of 8% per year is used for Government Water Schemes, with typically 6% and 10% sensitivity testing as well. For the purpose of this illustration the 8% per year discount rate is applied to obtain the PV for each of the sequences. This is also shown in Table 6-1 with respect to the first five sequences. A set of 995 PVs is thus obtained which can be further analysed as regards its statistical parameters.

The probability density function of the set of PVs, i.e. the number of events grouped in suitable intervals, e.g. 20 million m^3 in this case, is shown in Figure 6-3. The median value (i.e. exact midway in the ranking, being the 498th ranked event) is 165 million m^3, while the average (mean) was 185 million m^3. The standard deviation was calculated at 115 million m^3.

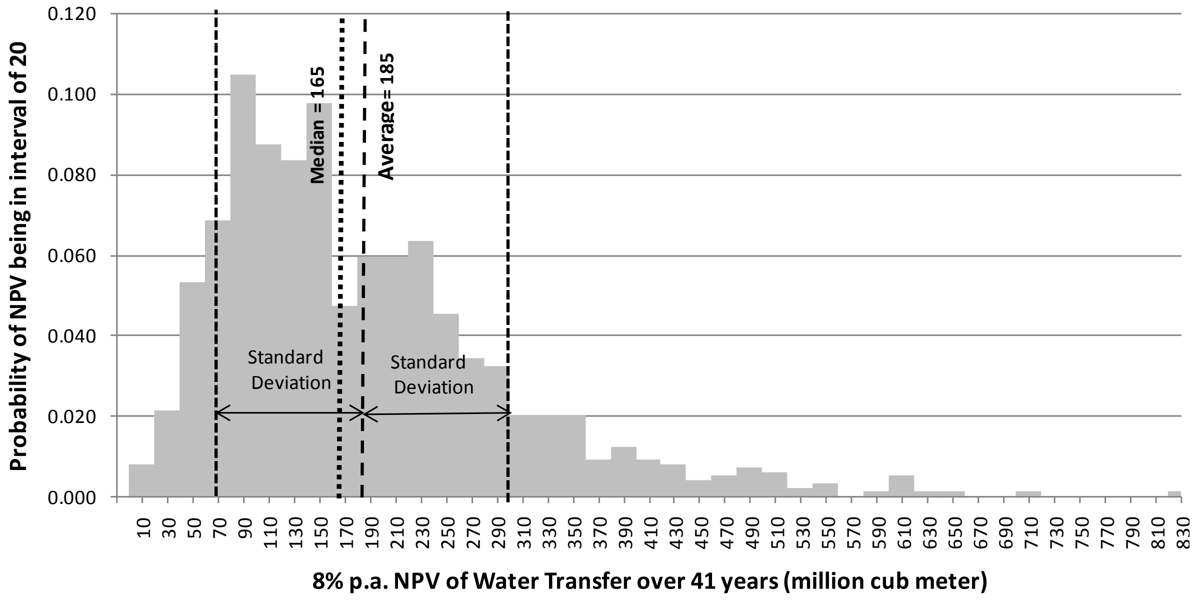

Figure 6-3: Probability density function of PVs of water transfers (8% discount rate and 2010 base year)

The 10th and 90th percentile points are, respectively, at 64.5 million m^3 and 332.0 million m^3.

6.4.2 Water transfer costs

As found in the case studies examined in Chapter 5, pumping costs often form a significant component of the life-cycle cost of an IBT project. In the case of the Thukela Water Project (see paragraph 5.8.2.3) the electricity cost to transfer 396 million m^3/a was calculated at R224.14 million/a, or 56.6 c/m^3.

Usually it is assumed that the unit cost would remain constant (in real terms) throughout the economic life of a project. In such cases it is a simplistic conversion from the results in paragraph 6.2 towards obtaining a probability density function of PVs of the cost of water transfer. Assuming, for purposes of illustration, electricity cost of 56.6 c/m^3 for the transfers in the example above, leads to the PVs for the first five sequences as shown in Table 6-2.

Table 6-2: PVs of electricity costs for first five of 995 sequences (8% discount rate, 2010 base year))

	Sequence 1 flows	Sequence 2 flows	Sequence 3 flows	Sequence 4 flows	Sequence 5 flows
Present value of pumping @ 8% p.a (Rand million)	145.17	40.85	114.61	111.39	132.86

The cumulative probability density function of PVs is illustrated in Figure 6-4 and the parameters for the full set of 995 sequences shown in Table 6-3.

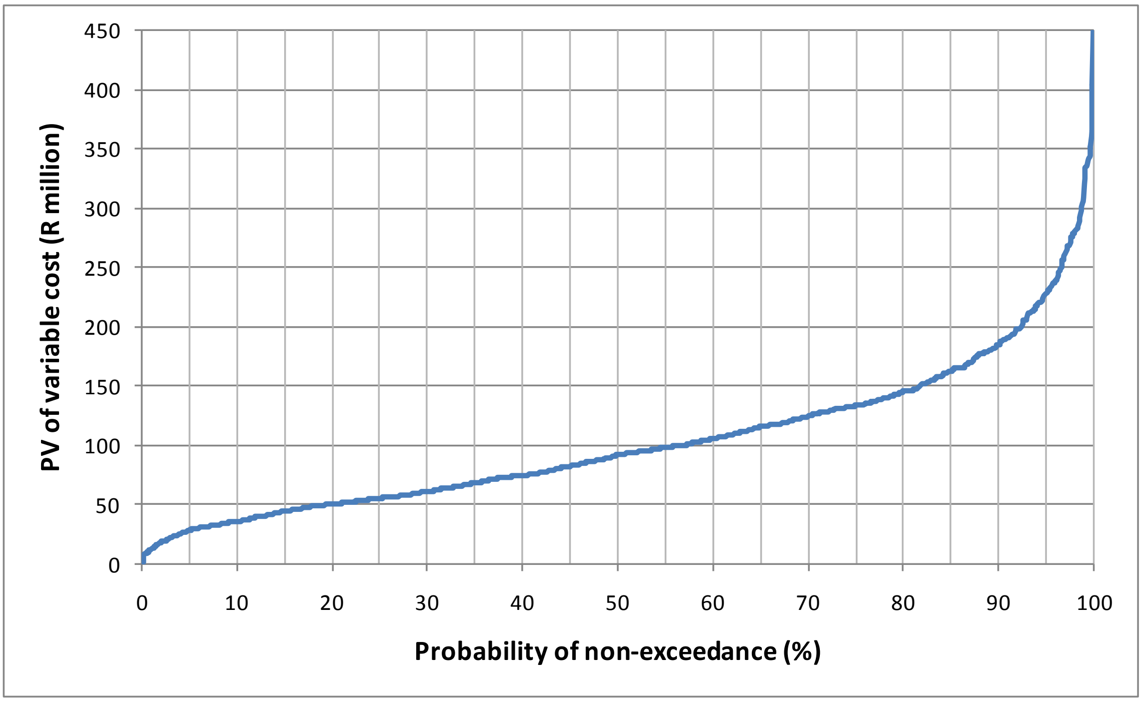

Figure 6-4: Probability of PV of variable costs for total set of 995 sequences (8% discount rate)

Table 6-3: Statistical parameters of electricity costs of set of 995 sequences of water transfers (8% discount rate)

Parameter	Present Value (R million)
Median	93.4
Average	104.7
Standard Deviation	65.1
Range: 10^{th} %	36.5
Range: 90^{th} %	187.9

If there is cause to believe that the applicable unit cost of electricity would change in the future, as was the case in RSA Case Study 3 where a 20% increase in tariffs was assumed for the first five years, the annual costs for each of the 995 records in the example must be determined and the probabilistic analysis applied in the same way as was done in paragraph 6.2 in respect of the quantities of water transferred.

6.5 Dealing with uncertainty in decision-making: choosing the appropriate PV of electricity costs

Having obtained the stochastic input regarding the cost of water transfers, usually the electricity costs to pump the water, the decision-maker now has to choose an appropriate variable PV, as input for further analysis. To assist with this, elements of decision analysis theory are applied.

As argued in paragraph 2.4, a government is normally considered risk-indifferent, and therefore assumed to be an expected value decision-maker: the expected value would be the unbiased rational choice exercised.

In Figure 6-4 the cumulative probability of non-exceedance of the PVs of the variable cost is shown. The expected PV of variable cost over the economic life of the project is its mean value, therefore R104.7 million. This would be the appropriate input (for a discount rate of 8%) for the variable cost into the economic model, i.e. the determination of the URV of the project.

6.6 Reassessing the URV method in view of stochastic water transfers

In the Incremental Approach to the appraisal of IBT projects the PV of total life-cycle costs, comprising all capital and running costs, suitably priced and discounted, is determined. In the preceding paragraphs it was demonstrated that an uncertainty exists regarding the volumes of water to be transferred into the future, which necessitates a stochastic approach to the modelling of the variable costs and, by implication therefore, too, the PV of the total life-cycle cost.

In the application of the Incremental Approach it is also generally assumed that the PV of the water transfers is the appropriate denominator to obtain the URV of the project. This assumption needs to be questioned in the light of the stochastic nature of the water transfers.

6.6.1 Description of the URV measure and its application with the Incremental Approach

The URV measure has its origin in the Department of Water Affairs (DWA) in the 1980s. It was conceptualised for use by planners of Government Water Works, these being public projects to assess best sizes, layouts and configurations of such schemes. The method of determining the URV is illustrated by means of Figure 6-5.

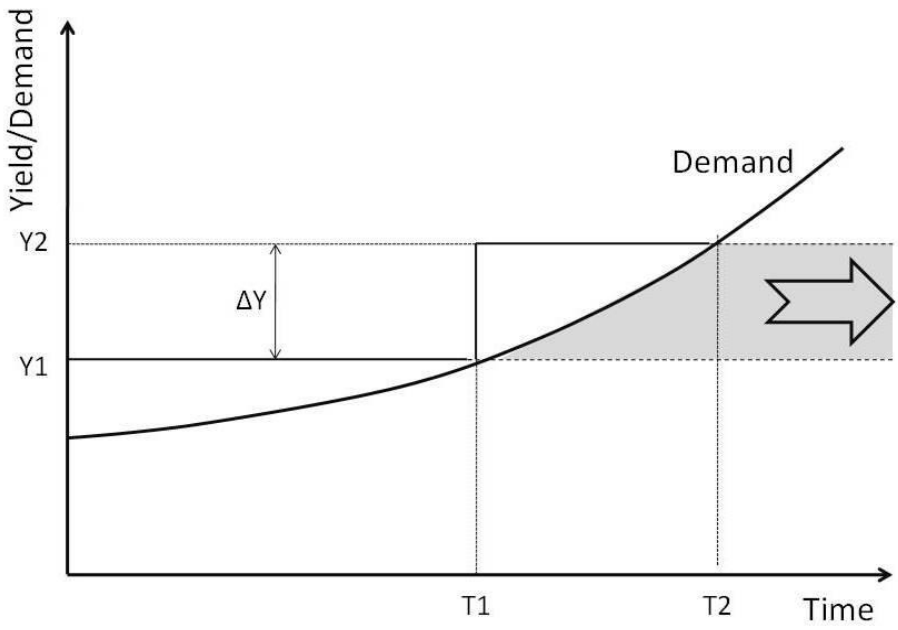

Figure 6-5: Meeting growth in demand by expanding the capacity of the system

The projected demand is estimated to equal, and thereafter exceed, the firm yield[11] of the existing system, Y1, at time T1. An intervention, such as the addition of an IBT project that increases the firm yield of the system by ΔY from Y1 to Y2, is required to ensure that growing demand is met after T1. This intervention will be sufficient until time T2 by which time another intervention will be required.

The augmentation project (the IBT in this case) is compared to other options by considering the capital and recurrent costs over the economic life of the project, discounted to PV. The economic life of large water infrastructure (such as dams) is assumed by the DWA as 45 years.

Recurrent costs often include variable costs; costs that are directly related to the water quantities delivered, such as pumping (energy), water treatment (energy and chemical) and royalty (international payment) costs.

Costs are determined at constant prices, adjusted to exclude any taxes and subsidies, sometimes also shadow priced to allow for market distortions, e.g. the cost of unskilled

[11] Firm yield is the maximum base yield that can be attained. Base yield is the minimum yield over a specified number of consecutive time intervals that can be abstracted from a river or reservoir system fed by a given inflow sequence while attempting to satisfy a given target draft associated with a specified demand pattern for water and a specified operating policy (World Meteorological Association [WMO], 2009:II.4-13).

workers in an environment of surplus labour but minimum wages. The value of such a cash flow stream at a specific point in time, usually present day, is determined using an economic discount rate, sometimes also called a "social discount rate". Any remaining value at the end of the discounted period is credited to the cost stream and accounted for in the discounting calculation.

The economic comparison of alternative water resource projects is done by examining their URVs. To determine the URV of a particular scheme, the water supplied is projected over the same period and discounted at the same rate as the costs to derive a "present value" in cubic meters. In this example, therefore, the total quantity of water supplied with the particular option is shown in the shaded area in Figure 6-5, i.e. the sum of all annual demands starting at time T1, growing till equalling the yield of ∆**Y** at time T2, and thereafter remaining constant until the end of the economic life of the scheme. The URV of the scheme is derived by dividing the PV of the costs with the PV of the water supplied as shown in Equation 1.

$$URV = \frac{PV\ of\ Costs}{PV\ of\ Quantity\ \ of\ water\ \ supplied} \qquad \textbf{Equation 1}$$

With the Incremental Approach the quantities delivered by a scheme influences its URV, not only because it forms the denominator in equation 1, but also because it could affect the costs (above the line) when operating costs vary with the quantities delivered, e.g. the variable costs where pumping is required.

6.6.2 Appropriate denominator of the URV

As was stated in paragraph 2.3, URVs provide a measure of cost vs. effectiveness and are therefore completely analogous in application to the CEA method. The assumption made in the IA was to equate the present value of water transfers with effectiveness. It should be noted that this is typically the kind of assumption made in CEA – whether the measure is "water actually delivered" (Herrington, 2006:257) or lives saved in the case of public health programmes (Boardman et al., 2011:464). The non-monetised measure of effectiveness is used as denominator in the cost-effectiveness ratio, e.g. Rands per m^3 or Rands per life saved.

The Incremental Approach assumes that future water transfers can be treated as deterministic inputs into the appraisal process, but it was demonstrated that these transfers are stochastic, i.e. non-deterministic. The question now arises whether it would be logical, in the situation of uncertainty regarding water transfers, to use the expected value of the water transfers as the measure of effectiveness, therefore the denominator.

Before answering this question it is advisable first to consider what exactly is meant by "effectiveness" when appraising the augmentation of an existing supply system. Fundamentally society and, by implication, the water resource manager, are interested in the availability of reliable water supplies into the future. Acceptable levels of reliability of water supply have to be established for a particular supply area before embarking on the process of planning an augmentation scheme.

In the RSA, priority tables that define required levels of security for categories of water users are used as inputs into the WRYM and WRPM simulation tools (see Basson et al., 1994:234-238 for detail). Elsewhere the objectives have been described as levels of service (LOS) criteria. The Government of Queensland, Australia, for instance, set LOS criteria for water supply to the Brisbane area not only in terms of the frequency of different levels of restrictions, but also in terms of the maximum durations of these restrictions (Queensland Government, 2006:44).

It is argued that, provided the reliability criteria are satisfied, i.e. not violated, a project that would meet the projected water demand for a certain period into the future can be considered "effective". An appropriate measure of effectiveness would be the incremental demand that is secured by means of the augmentation scheme – as projected. The latter qualification is required as it is assumed that the additional security of supply afforded by a project over the initial period until the growth in demand has "caught up" with the new system capacity (these projects typically being "lumpy") at time T1 in Figure 6-5, does not hold significant utility to the water users. If it had held significant utility, it could be reasoned, such utility would have found its way into the reliability criteria set *a priori*.

The conclusion from the above is that a good measure of the effectiveness of a project, that will increase the system capacity of supply from Y1 to Y2 as in Figure 6-5, is the additional water assured into the future by the project, i.e. the volume of water indicated in the shaded area. This, coincidentally, reflects the same quantities used in the IA, which was based, erroneously as was shown, on the assumption that these quantities were to be transferred in the future.

6.6.3 URV reviewed

In determining the URV of a potential IBT project, using the IA, the quantity of water used to calculate the PV of the life-cycle costs was also used in the denominator – as shown in Equation 1 in paragraph 6.6.1. The findings of this research have shown that this approach, where variable operating costs are stochastic in nature, as is usually the case with IBT projects – will lead to the wrong URV derivations.

The improved URV method of the Comprehensive Approach has the following equation:

$$URV = \frac{PV\ of\ life\ cycle\ costs}{PV\ of\ quantity\ of\ water\ incrementally\ assured} \qquad \textbf{Equation 2}$$

where

$PV\ of\ life\text{-}cycle\ cost = PV_{capital\ costs} + PV_{O\&M\ costs}$

and

$PV_{O\&M\ costs} = PV_{maintenance\ costs} + PV_{fixed\ operating\ costs} + Expected\ PV_{variable\ operating\ costs}$.

6.6.4 Application

The value of the Comprehensive Approach can be demonstrated by undertaking an actual evaluation of a case, and comparing the results to those found by means of the IA. For that the *Comparative Study*, referred to earlier in 5.8.1 and 6.2, is used in the next section.

6.7 Demonstrating the application of the Comprehensive Approach

The *Comparative Study* (DWA, 2010e) compared a second phase of the LHWP against further importation of water from the Thukela River. For convenience some detail regarding this study, which is used to demonstrate the application of the Comprehensive Approach, will be repeated.

6.7.1 Background

The LHWP originated from the signing of a treaty between South Africa and the Kingdom of Lesotho on 24 October, 1986 (Tromp, 2006:n.p.). The first phase, completed in 2004, comprised two large dams in Lesotho at Katse and Mohale, a river diversion works at Matsoku, and an extensive tunnel system to collect the water into Katse Dam and convey it further to the Ash River in South Africa. On the way hydro-electric power is generated at Muela in Lesotho. Already in the treaty a number of further phases were foreseen. A feasibility study of the second phase (LHWP II) was undertaken by the Lesotho Highlands Water Commission and it recommended the building of a large dam at Polihali in Lesotho, with connecting tunnel to Katse Dam (LHWC, 2009:58). DWA subsequently undertook a study to compare the proposed LHWP II against a possible project to augment the Vaal River from the Thukela River – the TWP (DWA, 2010e).

The alternative TWP comprised the construction of a large dam at Jana on the main stem of the Thukela River, the Mielietuin Dam on the Bushman's River, pumping stations and aqueducts to transfer the water to Sterkfontein Dam as an extension of the existing Tugela-Vaal GWS. This latter scheme was completed in the 1980s and makes use of Eskom's

Drakensberg hydro-electric pump storage scheme to transfer up to 20 m^3/s to Sterkfontein Dam in the upper reaches of the Vaal River System (DEA, 1984).

Due to its elevation the LHWP II will operate entirely under gravity. The transferable yield that can be made available is 437 million m^3/a, or 13.86 m^3/s. The TWP, in contrast, is much lower than the Vaal River basin and therefore requires pumping to overcome the difference in elevation of some 1030 m. The transferable yield of the TWP, with only a large Jana Dam in place – for purposes of comparison of options - was estimated at 396 million m^3/a, or 12.55 m^3/s.

The locality of the two options, the LHWP II and the TWP, is shown in Figure 6-1.

As the LHWP II scheme will reduce the yield of the downstream Orange River System, measures will be required to compensate for this effect. For that reason an additional future dam on the Orange River at Vioolsdrift was postulated and its cost included in that alternative.

6.7.2 Water requirement scenarios

As previously described in paragraph 5.8.2.1 the *Comparative Study* used water requirement scenarios derived from an earlier study by the DWAF – the Reconciliation Study for the Vaal River System. Two of these were used for final comparison purposes; the base demand scenario and a high demand scenario, both without the inclusion of re-use of effluent.

For the purpose of this review only the high demand scenario – the D3L4High scenario – will be used. (The D3L4High scenario is described in more detail in paragraph 5.8.2.1.)

6.7.3 Results from the *Comparative Study*

The *Comparative Study* detailed all capital, operating and maintenance costs. Prices were based at October 2007 levels. As it was an economic comparison, VAT was excluded, being considered as a transfer cost, and therefore not applicable within South Africa and thus the TWP. As regards the LHWP II, the Lesotho Treaty explicitly excluded all taxes related to the implementation of the project.

In the case of the LHWP royalties are payable to Lesotho. These were originally based on an agreed sharing between the two countries of the benefit of undertaking the LHWP as opposed to the best alternative project. The latter was construed, at the time of negotiation in the 1980s, as a scheme to transfer an equivalent quantity of water from either the Orange River below Lesotho to the Vaal River – the Orange Vaal Transfer Scheme (OVTS) – or a combination of that scheme and further augmentation from the Thukela River.

The *Comparative Study* included an analysis of the impact on royalty payments to Lesotho if LHWP II goes ahead as opposed to the TWP. The cost impacts have been included in the results of the study.

For the high demand scenario the costs of the elements of the LHWP II and the TWP are shown in Table 6-4 and Table 6-5 respectively (DWA, 2010h:8-9).

Table 6-4: Capital cost of LHWP Ph II (October 2007 Rands)

Element	Civil R'000	M&E R'000
Polihali Dam FSL 2075	2 060 112	20 839
Polihali/Katse Tunnel	1 676 282	70 179
Roads and bridges	622 482	0
Power supply and telecoms	150 629	30 216
Camps	185 848	0
Vioolsdrift Dam (incremental)	600 000	10 000
Total	**5 295 353**	**131 234**

Table 6-5: Capital cost of Thukela Water Project (October 2007 Rands)

Element	Civil R'000	M&E R'000
Jana Dam FSL 890	5 728 300	322 400
Pipelines - Jana to Kilburn (Q = 12,55 m^3/s)	3 425 900	0
Pump stations - Jana to Kilburn (Q = 12,55 m^3/s)	88 400	395 800
Roads	182 144	0
Total	**9 424 744**	**718 200**

The appraisal in the *Comparative Study* followed the Incremental Approach regarding the TWP option, as was shown for the RSA Case Study 4 in paragraph 5.8. The discounted life-cycle costs and water transfers of the TWP and the LHWP II are shown in Table 6-6 and Table 6-7 respectively.

Table 6-6: High demand: TWP with Jana Dam FSL 890 costing and estimated water transfer

Discount rate		0%	6%	8%	10%
PV Life cycle costs	R million	20 254	9 248	7 559	6 290
PV Water transferred	million m^3	13 748	2 330	1 424	906

Table 6-7: High demand: LHWP (including royalties) costing and estimated water transfer

Discount rate		0%	6%	8%	10%
PV Life cycle costs	R million	18 029	8 055	6 606	5 533
PV Water transferred	million m^3	14 729	2 436	1 478	934

From the above tables the URVs were determined, as shown in Table 6-8.

Table 6-8: High demand: URV results (Rand/m^3)

Scheme and scenario	Discount Rates		
	6%	8%	10%
Thukela Water Project: Jana Dam at FSL 890	3.97	5.31	6.94
LHWP Phase II with incremental Royalties: Polihali Dam at FSL 2075	3.31	4.47	5.92
LHWP Phase II (excluding effect of incremental Royalties): Polihali Dam at FSL 2075	1.96	2.81	3.87

For the base demand scenario similar analyses were undertaken. The resultant URVs are provided in Table 6-9.

Table 6-9: Base demand: URV results (Rand/m^3)

Scheme and scenario	Discount Rates		
	6%	8%	10%
Thukela Water Project: Jana Dam at FSL 840	4.69	6.58	9.03
LHWP Phase II with incremental Royalties: Polihali Dam at FSL 2075	5.53	7.80	10.80
LHWP Phase II (excluding effect of incremental Royalties): Polihali Dam at FSL 2075	3.22	4.80	6.91

The *Comparative Study* concluded that the two schemes, the LHWP II and the TWP, are very close economically. For the high demand scenario and with the inclusion of the royalty payments, the LHWP II scheme came out more favourable, whereas the TWP was more favourable for the base demand scenario.

For purposes of this example only the high demand scenario is taken forward as the systems analysis data, referred to in paragraph 6.2, were available only for that scenario. Note that this demonstration concentrates further on the application of the Comprehensive Approach, as opposed to the Incremental Approach, on the TWP option, as the LHWP does not incur pumping costs.

As was noted in the RSA Case Study 4 regarding the TWP, electricity costs were not shadow priced. A correction in this regard was therefore firstly required.

6.7.4 The TWP option shadow priced for electricity costs

A shadow price for electricity was recently derived for a study into future marginal costs of water for South Africa (DWA, 2010f:7). It was based on the assumption that all new generation until 2019 would be from coal-fired power stations at R0.60 per kWh and from 2020 onwards all new generation will be by nuclear power at R1.20 per kWh. For the purpose of this analysis a blend of nuclear and coal generation is assumed at a marginal rate of R0.90 per kWh. A 5% addition to cater for transmission costs was also recommended (2010f:B1). These costs were effective for mid-2009 Rand values. As the base date of pricing of the *Comparative Study* was October 2007 an adjustment was also required to bring the shadow price to the latter date. The consumer price index (CPI) increased at about 15% over the intervening period (2010f:8). The effective shadow price of energy (including transmission costs) for the base date of October 2007 was therefore determined as being 82.2 cents per kWh.

Replacing the price of electricity, averaging 16.2 cents per kWh in the High Demand scenario analysis spreadsheets of the *Comparative Study* (DWA, 2010h: Appendix A2), by the above shadow price, results in URVs for the TWP as shown in Table 6-10. (Further detail regarding the derivation of these URVs are provided in ANNEXURE 6-B.)

Table 6-10: URVs for TWP with high demand and electricity shadow priced: Incremental Approach

Discount rate		**6%**	**8%**	**10%**
PV of life cycle costs	R million	14 609	10 836	8 375
PV of water transferred	million m^3	2 330	1 424	906
URV	R/m^3	6.27	7.61	9.24

Note that only the TWP option is affected by the shadow price adjustment – the results for the LHWP Phase 2 option remained as in Table 6-8, as the latter option does not incur pumping costs.

6.7.5 Stochastic water transfers costs included in the TWP (shadow priced)

As argued in paragraph 6.2, the 995 stochastic transfer sequences, generated synthetically for the LHWP II and applying to the high demand scenario, can be considered applicable to the TWP for demonstration purposes.

From the 995 records of 41 years each, 995 PVs of the water quantities transferred were determined for discount rates of 6%, 8% and 10% (see ANNEXURE 6-A). The average (mean) values, being the expected PVs as discussed in paragraph 6.5, are shown in Table 6-11.

Table 6-11: TWP: Expected PV of 41 years of water transfers, starting in 2010 and ending in 2050

Expected value at discount rate in million m^3		
6%	8%	10%
335.3	**184.8**	**104.9**

For comparative purposes these PVs need to be further discounted to October 2007, the base date of the *Comparative Study*. The results are shown in Table 6-12.

Table 6-12: TWP: Expected PVs of water transfers with base date Oct 2007

Expected PV at discount rate in million m^3		
6%	8%	10%
298.4	**158.4**	**86.7**

These PVs can be compared to the discounted PVs used for the water transfer in the *Comparative Study*. As can be seen from ANNEXURE 6-B, as well as Table 6-13, the discounted PVs of the water transfers of the *Comparative Study* are much higher than those derived in Table 6-12.

The discounted PVs of the water transfers of the *Comparative Study* can also be compared to the stochastic sequence with the highest PVs; sequence number 410 (out of the 995 sequences) in Table 6-13. (See the detail of sequence in ANNEXURE 6-D.) Note that the base date of the stochastic sequence had to be brought in line with that of the *Comparative Study.*

Table 6-13: PV of water transfers of *Comparative Study* against PV of highest stochastic sequence

	PV at discount rate in million m^3		
	6%	8%	10%
PV value of water transfers in *Comparative Study,* i.e. following the Incremental Approach	2 330	1 424	906
PV of stochastic sequence with highest transfers	1257	844	588
PV of stochastic sequence with highest transfers (corrected base date)	1119	724	486

Table 6-13 illustrates the pessimistic overestimation, or extreme bias, of the PV of the water transfers in the *Comparative Study,* in following the Incremental Approach. At 8% discount rate, the PV of 1 424 million m^3 used in the latter study is almost twice the 724 million m^3 of the highest PV of the 995 stochastic sequence, i.e. the one with a 99.9 percentile of the probability of exceedance.

The analyses of the TWP in paragraph 6.7.4 is adapted by replacing previously determined pumping costs with those associated with the expected present values of water transfers in Table 6-12. As the South African government is considered an expected value decision-maker, the resultant values are accepted as fair representation of pumping costs to use for the appraisal of the project.

The results are detailed in ANNEXURE 6-C and summarised in Table 6-14. Note that, for the determination of the URV, the PV of the effectiveness of water supply, being the incremental water assured, was applied as denominator in the equation, as set out in paragraph 6.6.2.

Table 6-14: URVs for TWP, high demand, with stochastic water transfers and electricity shadow –priced: Comprehensive Approach

Discount rate		**6%**	**8%**	**10%**
Expected present value (Oct 2007) of water transfers	million m^3	298	158	87
PV of fixed costs	R million	7 930	6 753	5 777
PV of variable cost	R million	855	454	249
PV of life-cycle costs	R million	8 785	7 207	6 026
PV effectiveness of water supply	million m^3	2 330	1 424	906
URV	R/m^3	3.77	5.06	6.65

With the electricity cost correctly shadow priced the sensitivity of the URV results become very apparent; for the 8% discount rate it moved from R7.61/m^3 in using the Incremental Approach in Table 6-10 to R5.06/m^3 for the Comprehensive Approach in Table 6-14 – a significant change. Similarly, the PV of the estimated life-cycle cost for the TWP option moved from R10 836 million down to R7 207 million – a 33% reduction.

6.7.6 The stochastic range of the URVs of the TWP

The outcome of the economic modelling has been tested for the 10th and 90th percentile points of probability function of the PV of water transfers, as recommended by Matheson and Howard (1983:28) (see paragraph 2.4). The results for the 8% discount rate only are provided in Table 6-15.

Table 6-15: Range of results of URVs for TWP High Demand Comprehensive Approach at 8% discount rate

		Range	
	Units	**10th Percentile**	**90th Percentile**
PV of water transfers	million m^3	55	285
PV of fixed costs	R million	6 753	6 753
PV of variable cost	R million	159	816
PV of life-cycle costs	R million	6 912	7 569
PV effectiveness of water supply	million m^3	1 424	1 424
URV	R/m^3	4.85	5.31

The results as summarised in Table 6-14 and Table 6-15 are compared with the LHWP Phase 2 alternative for the high demand scenario. With a URV of 4.47 (Table 6-8) and a PV of life-cycle costs of R6 606 million (Table 6-7), it can be seen that the LHWP Phase 2 dominates the TWP over its full stochastic range. For this scenario the LHWP II is therefore economically more efficient than is the TWP option. While the base demand scenario has not been similarly analysed, it can be expected, inferring from Table 6-9 that the results would not be as unambiguous as was found for the high demand scenario.[12]

6.8 Conclusions regarding the development of the Comprehensive Approach

It was shown by means of an example that existing modelling tools, such as the WRPM, can be employed to obtain simulated sequences of future water transfers of IBT schemes under

[12] The South African government decided on the implementation of the LHWP II as the next augmentation option for the Vaal River supply area. In this regard, it formally entered into an agreement with Lesotho on 11 August, 2011.

consideration. With stochastic hydrological data input the transfer data sequences thus generated will exhibit characteristics similar to water transfers of existing IBT projects.

Also demonstrated was the derivation of stochastic sequences of the variable operating costs and their PVs. With the aid of decision analysis theory it was shown that the expected PV of the life-cycle costs would be acceptable. The expected value cost would then be included as nominator in the URV equation.

Examining the URV measure in terms of its underlying CEA economic theory revealed that a good measure of effectiveness would be the incremental water availability assured by the expansion of a system and bounded by the projected demand curve until full capacity is reached. The PV of the annual quantities of water thus assured is used as denominator in the URV equation.

The Comprehensive Approach has brought clarity to the application of the URV measure in appraising water resource capacity expansion projects. It is a new generalised approach that explicitly provides for the inclusion of uncertainty of input costs.

Whereas only the uncertainty due to hydrologic probabilities inherent in water resource projects was addressed in developing the Comprehensive Approach, it can be noted that other uncertainties, e.g. regarding capital costs, can also be provided for. Generally, though, the outcome should first be tested for its sensitivity to a change in the value of a particular variable. If it remains stable, there would be no need to proceed to a more detailed appraisal model by including probabilistic modelling of that variable.

To conclude the chapter the effect of the Comprehensive Approach, as opposed to the Incremental Approach of a large IBT project, the Thukela Water Project (TWP), is summarised in Table 6-16.

Table 6-16: Summary of comparison of Incremental Approach with Comprehensive Approach applied to the TWP (for 8% discount rate)

		URV	**PV of life-cycle costs**
		R/m^3	R million
Incremental Approach		7.61	10 836
Comprehensive Approach	Expected	5.06	7 207
	Stochastic range	4.85 – 5.31	6 911 – 7 569

The impact of the cost of transferring the water to the Vaal River basin over the life-time of the project was demonstrated to be significantly lower with the Comprehensive Approach than estimated with the Incremental Approach. It is concluded that the latter approach holds significant risks that sub-optimal, therefore poor, implementation decisions can result.

7 Findings, conclusions and recommendations

This chapter summarises the findings of the study, draws conclusions and makes recommendations for further action and research.

7.1 Background of problem, hypotheses and rationale

South Africa has a number of IBT projects that have been in operation for more than twenty years. Some of these transfers involve pumping of the water against high heads, incurring considerable variable[13] operating costs. Having been a relative fore-runner in this regard, South Africa also made notable advances in modelling complex water supply systems early on.

Examination of the transfer records of a selection of IBT projects showed that actual transfers were significantly different to what was envisaged when the projects were appraised in their planning stages. Not only were the transfers quite erratic, but the actual quantities transferred were considerably less than originally foreseen. This raised the question as to whether the appraisal method used was sufficiently robust to deal with IBT projects that incur significant variable costs. The corollary to this question was whether the same method – called for the purpose of this study the Incremental Approach – is still followed.

The main hypothesis was formulated that *the Incremental Approach to appraise IBT options to augment existing water resource systems was too simplistic in certain cases and could lead to wrong conclusions*. This statement was broken down into three sub-hypotheses, and further described in four research questions, as follows:

> *Sub-hypothesis 1:* The Incremental Approach of IBT project appraisal does not adequately consider receiving catchment conditions and a comprehensive systems simulation is required at project appraisal stage if variable costs (e.g. pumping costs) are associated with water transfers.
>
> *Sub-hypothesis 2*: The Incremental Approach is generally being applied in the appraisal of IBT projects.
>
> *Sub-hypothesis 3*: The URV method to derive the relative economic viability of an IBT project, and which forms part of the Incremental Approach, requires greater conceptual clarity.

[13] 'Variable', as these costs are directly related to the quantities of water transferred.

Question 1: Why are there differences between the projections of water transfers at the planning stage and the actual transfers after implementation of an IBT and does it indicate an inadequacy of the Incremental Approach (IA) of project appraisal?

Question 2: How generally is the IA applied?

Question 3: How can the IA be improved to predict water transfers with greater realism?

Question 4: How must the URV methodology consequently be improved?

The study set out to prove or disprove the main hypothesis on the basis of responding to these sub-hypotheses and research questions.

The importance of having a robust methodology to appraise IBTs follows from the very high capital, as well as operating, costs typically associated with these projects. A sub-optimal decision can have severe cost implications. As the RSA is relatively water scarce the incremental costs of water already are relatively high. Other measures, such as water demand management, are increasingly employed to reconcile demand and supply, but the need remains for more IBT projects in the future. Internationally, too, a number of IBT projects are being contemplated (see paragraph1.2.2).

7.2 Mismatches between predicted and actual water transfers

The first sub-hypothesis was addressed by undertaking a detailed case study in chapter 4 of the water transfers from the Heyshope Dam on the Assegai River to the Grootdraai Dam on the Vaal River – the Usutu-Vaal GWS (Second Phase). Possible causes for the reduced and erratic nature of the actual water transfers, such as slower growth in demand, physical changes to the supply system, shortages of water due to droughts or pumping capacity issues, were probed. Even after accounting for such factors a sizeable difference between predicted and actual transfer volumes remained unexplained. A detailed examination of the year-to-year operational decision-making of the supply system therefore followed.

The history of annual operating decision-making was reconstructed in paragraph 4.3.5 for 22 years of available record of the IVRS – which included the Usutu-Vaal GWS – from the annual operational analysis reports. These annual operating analyses were undertaken using the South African developed system simulation tools. Annually the ability of the water supply system to meet water requirements for a number of years into the future was determined. The state of the system, i.e. how much water was in storage, and the water needs at the various delivery points in the system, were important inputs. The risk of curtailments in the short to medium term was assessed and recommendations, also taking into account variable cost implications, were made. Typically, if the system was in a good state, i.e. the dams were fairly full and risks were shown to be low, expensive water transfers were avoided.

The examination of the 22 year record showed that the decision to pump water from the Heyshope Dam into the Vaal River was strongly associated with the state of the Grootdraai Dam in the receiving catchment. This pointed to the cause of the problem of the mismatch between planned and actual transfers – that the Incremental Approach led to an imprecise prognosis of likely future water transfers.

Further support for this finding came from examining the transfers of the Tugela-Vaal GWP in paragraph 4.4. In this case, too, far less water was transferred than had originally been projected. While a lack of actual transfer records caused some difficulty in the analysis, the releases from Sterkfontein Dam in support of the Vaal River Supply System had been far less than predicted. In the source catchment it was also found that the actual water level regime in Woodstock Dam, the main source of water for the project, was significantly higher than was predicted at the planning stage.

Examining the annual operating analysis reports for the 22 years on record showed that the state of the system determined whether or not pumping from the Thukela River to the Vaal River basin was required. This reinforced the finding regarding the Usutu-Vaal water transfers.

The first sub-hypothesis could therefore be supported: the Incremental Approach of IBT project appraisal, as had been historically applied, did not consider receiving catchment conditions adequately. A comprehensive systems simulation, which includes both the source and receiving systems, needs to be undertaken at project appraisal stage, particularly if significant pumping costs are associated with water transfers, in order to obtain a realistic perspective of the transfers likely to take place after construction of an IBT.

7.3 Pervasiveness of the Incremental Approach

To test the second sub-hypothesis, that the Incremental approach is still generally being applied, six case studies were undertaken in Chapter 5 – four from South Africa, one from the Peoples' Republic of China and one from Australia. The South African cases were selected on the basis of available information, a representative spread of recognised professional practitioners and how recent they were. The international cases were selected on the basis of available information, and after much searching.

The four South African cases each involved an investigation into options to augment the water resources of an existing water supply system by a possible inter-basin transfer. The reports on these investigations were examined to establish the methodology each followed in appraising possible IBT projects. It was found, for each case, that:

a) Simulation modelling was undertaken to establish the available yield of the existing system
b) Simulation modelling was undertaken in the source catchment to establish the available yield that could be transferred
c) The water to be transferred annually was assumed to be equal to the deficit predicted for that year in the future, capped by the available transfer yield when the deficit reached and exceeded the yield
d) The annual transfer costs were directly related to the quantities being transferred
e) The economic evaluation was based on the comparison of either the URVs or discounted present values of the alternative augmentation options.

All four cases, in the appraisal of the IBT projects under consideration, followed the Incremental Approach.

The first of the international case studies, the Wanjiazhai Water Transfer Project in China, was based on documents compiled pre and post the implementation of the project by the World Bank. It was found that:

a) The transfer project was expected to provide all incremental water beyond the yield of the receiving basin
b) Annual transfers would exhibit a pattern of smooth growth, coinciding with water demand growth, until capped by the transfer capacity of the scheme
c) Costs to transfer the water were directly related to the annual quantities being transferred
d) These costs were included in the economic appraisal.

The second international case study concerned recent investigations undertaken of options to augment the water resources of the South East Queensland (SEQ) water supply system – the city of Brisbane being the largest consumer. Examination of the SEQ reports showed that limited systems analysis methodology was applied. The water availability from existing resources was determined by means of basic analysis procedures. The determinations of the additional availability of yield from potential augmentation options were not done in a systems context. Like with the previous case studies it was found, by inference from contextual analysis as not all data were reported, that the assumption was made that all water requirements beyond existing system yield capacity had to be provided from new resources.

The SEQ case study demonstrated that the approach applied in Australia in the last decade was analogous to the Incremental Approach.

The two international case studies did not disprove the second sub-hypothesis.

Considering the integrated nature of the water resource profession – a number of the South African service providers are part of international consultancies in the field, and inter-linkages and information flows in the international academic and professional environment – it can be concluded that the current use of the Incremental Approach is pervasive, in South Africa as well as internationally.

7.4 From Incremental to Comprehensive Approach

Having established that the existing Incremental Approach to appraise IBT projects is flawed, but in general use, the next step was to propose a new approach in chapter 6. This is called the *Comprehensive Approach*.

7.4.1 Integrated systems analysis

The Comprehensive Approach proposal entailed, firstly, the undertaking of an analysis of the system with the inclusion of the expansion by means of the proposed IBT project. The analysis involved generating, by means of synthetic hydrology as input, a large number of simulation runs. For each of these the annual water transfers by means of the IBT scheme were extracted. It was found that the resulting transfer sequences exhibited patterns and characteristics similar to those actually experienced in real life, giving confidence in the applicability of the modelling that included simulating annual operating decision-making. The research question, “How can the IA be improved to predict water transfers with greater realism?” was thus responded to.

7.4.2 Variable costs

The next step was to determine, from the water transfer data, the annual variable operating costs, typically being the cost of pumping the water. The present value of the variable costs was determined for each sequence and, being stochastic in nature, decision analysis theory was applied to select an unbiased present value for use in the appraisal process, called the certain equivalent of the variable costs. It was shown how the sensitivity for the selection of the certain equivalent can be tested by repeating the appraisal for a range for the 10th and 90th percentile probability cases.

7.4.3 Unit reference value (URV)

The generally used unit reference value (URV) measure for appraising and ranking water resource projects in South Africa is rooted in economic theory – more particularly in the theory of cost-effectiveness analysis – as a result of this research. The common equation for the URV has been expanded and improved in paragraph 6.6 to distinguish between water transfers and the effectiveness of an IBT project. As similar measures to the URV are employed internationally, e.g. the discounted unit cost (DUC) measured used in Britain as described in paragraph 2.3, this constitutes a substantial contribution to the approach for appraising IBT projects in the future.

The research up to this point responded to sub-hypothesis 3, confirming that the URV measure required greater conceptual clarity, and also answered research question 4, “How must the URV methodology consequently be improved?”

7.4.4 Demonstrating the Comprehensive Approach

The result of applying the Comprehensive Approach, as opposed to the Incremental Approach, was demonstrated in paragraph 6.7 by means of an example with significant pumping costs associated with water transfers. It was shown that the Incremental Approach is severely biased with respect to variable costs and that this bias leads to significantly different estimations of likely life-cycle project costs. Such differences conceivably lead to suboptimal decision-making.

7.5 Recommendations

It is recommended that, to allow for uncertainties regarding future water transfers that would attract significant operating costs, the Comprehensive Approach always be followed when appraising potential IBT projects. In addition, when applying the URV for ranking IBT options, a separation is always required between water transfers affecting operating costs and water transfers used as a proxy measure for effectiveness.

A number of other observations that require further attention were made during the study. These are listed in the order from the more general to the particular, as follows:

a) Issues regarding the information systems of the Department of Water Affairs:
    i. During the investigation it was found that some inter-basin transfer data, such as the monthly quantities of water transferred between the Thukela basin and the Vaal basin and the transfers from Heyshope Dam to Morgenstond Dam, were not recorded in the hydrological information system (HIS). It is recommended that, in future, all inter-basin transfer data be captured.

ii. Two of the historic Annual Operating Analysis reports could not be found – not in the archives nor elsewhere. The archives consulted were not in a good state generally. It is recommended that the maintenance of these depositories be upgraded.

b) In the case study of the proposed Crocodile-Mokolo IBT (see paragraph 5.7), which is still under consideration, it was noted that:

   i. The economic costing model required correction regarding shadow-pricing. Water tariffs are generally viewed as transfer costs (economically speaking). Also, the cost of phosphate removal, included in the possible transfer of effluent water from the Vaal basin to the Crocodile Basin, may in any event be required in the Vaal basin in future and, if so, would not constitute an additional cost.

   ii. The Comprehensive Approach should be applied as it could affect the decision-making regarding the viability and sizing of the project.

c) Further towards the Crocodile-Mokolo IBT:

   i. For scenarios where it is necessary to augment the system by transferring water or effluent from the Vaal basin into the Crocodile basin, the Comprehensive Approach should be expanded to include this IBT as well.

   ii. The Comprehensive Approach should be applied to investigate whether increasing the capacity of Mokolo Dam, by raising it, would be an economic proposition.

d) In all four the South African case studies, electricity costs were based on published Eskom tariff structure. This pricing was not correct as the unit electricity cost should have been shadow priced in line with its projected marginal cost, as described in paragraph 6.7.4. Attention should be given to correct shadow pricing in general, and electricity in particular, in future appraisal studies.

7.6 Recommendations for further research

The following needs for further research, flowing from this work, were identified:

a) Appropriate institutional and financial models related to IBT projects should be investigated. The results from this study have shown that the financial viability of ring-fenced IBT projects could be misjudged if the income stream should be tied to the quantity of water transferred, as was the case with the Wanjiazhai project in the Peoples' Republic of China. This points towards a systems approach for cost recovery through water tariffs as well as associated institutional designs.

b) The usual position, after an augmentation scheme has been implemented and until it is fully utilised, is that the system enjoys a higher level of security than the level-of-service standard required. This additional security should give the water users an added utility, which may have a significant value. This may present a benefit which is not usually quantified and included in the appraisal of water resource projects. It was also not included in the Comprehensive Approach presented here. This aspect should be investigated to see if it has significance for adjusting the appraisal approach.

c) Water requirement projections are normally conservative in order to ensure that augmentation schemes or measures come on line in good time. The same growth curve is used for the determination of likely quantities of water to be transferred by an IBT in future, as demonstrated in this study, and to approximate the effectiveness of the project. It could be argued that, for the assessment of the likely volumes of water to be transferred, it may be more appropriate to use a probable, i.e. most likely growth, scenario as that would be commensurate with the route a risk-indifferent decision-maker will take. This should be investigated further.

d) The usual assumption is that the government of a country, due to its size in the economy, would be neutral to risk and can therefore be treated as an expected value decision-maker. While this would generally be a reasonable assumption, the situation may arise for small and/or developing countries where the implementation of an IBT may mean that a significant portion of its available budget will be consumed, that governments would tend to move towards being risk-averse and then the assumption no longer holds. The certain equivalent for such a government would be at a point away from the expected value – the difference being the risk premium as described earlier. This is an issue that requires further investigation as it can affect recommendations for decision-making.

e) The insights gained from the Comprehensive Approach should be expanded to cover the configuration and design of water supply systems. These would include the following:

   i. The positioning of a water treatment plant can make a significant difference to the operation, and therefore the operational cost, of a system. If, for instance, a WTP is placed at the source of an IBT and purified water, instead of raw water, is being transferred, the IBT operation would of necessity be locked to the purified water requirement and treatment capacities of the system. If the WTP can be placed in the receiving basin, where raw water can be brought in from various resources, greater flexibility will be gained. Applying the Comprehensive Approach may indicate significant advantages to the operational cost. Where a choice needs to be made between placing a WTP at a point where several resources can be utilised (which usually will mean expanding an existing WTP), as opposed to having a new WTP reliant only on the IBT, it would be very important to correctly estimate the variable costs of the IBT.

ii. The provisioning of additional capacities in a water supply system, e.g. in conveyance structures and WTPs, to provide for greater flexibility of operation may be indicated, following the Comprehensive Approach.

iii. Similarly, when considering a sea water desalination plant to augment an existing supply system, and applying the Comprehensive Approach, the advantages of a flexible operation regime, with the inclusion of the desalination plant, is likely to come to the fore. Such flexibility will allow the supply system to utilise the secondary yield of the cheaper, usually surface water, resources. Further research regarding the flexibility of various desalination technologies is indicated. Also, sea-water desalination plants are often promoted as ideal for private-public type (e.g. build, operate and transfer, or BOT) projects. Research into appropriate institutional funding options for desalination plants will assist with decision-making in this regard.

iv. There may be value in increasing the capacities of the dams to utilise more of their secondary yields where such utilisation is associated with low operational costs.

f) Applying the Comprehensive Approach leads also to a better understanding of the future state of the dams in the source catchments – the characteristics of the water levels and spills from the dams, as was seen in the case of the Woodstock Dam on the Thukela River. These characteristics may in turn affect considerations such as environmental impacts due to such dams and the opportunities for recreation. These require further investigation.

g) Following the Comprehensive Approach implies undertaking an integrated systems analysis comprising the entire water supply system, with the inclusion of the system that is envisaged to be linked. This may become a very complex, and expensive, undertaking. In addition, when the demand curve requires subsequent phases to follow in the short to medium term, planners may need to consider including scenarios of such phases from the outset, especially if such phases could have lower variable operating costs. There may be opportunities for simplifying the approach, such as reducing the boundaries of the receiving system. In the case of the Usutu-Vaal IBT (see paragraph 4.3.6) it was seen that a reduced system consisting of Heyshope, Zaaihoek and Grootdraai Dam subsystems would significantly reduce complexity, but give the realism sought for accurate planning purposes. Optimisation techniques could also be explored and, by analysing different practical cases, the sensitivity of the URV to variable cost as a proportion of total project cost, determined. Further such investigations and guidance regarding simplifying the Comprehensive Approach, especially for application during pre-feasibility stages of investigation, is recommended.

h) The report *Assessment of the ultimate potential and future marginal cost of water resources in South Africa* projected capital investments as well as operating and maintenance costs into the future. Figure 7-1 illustrates how the operation and maintenance costs are projected to grow (DWA, 2010f:40). The bulk of the growth depicted is ascribed to increased electricity cost as a result of larger pumping and desalination requirements. As these estimations were based on implicit application of the Incremental Approach these should be reviewed, applying the thought processes of the Comprehensive Approach.

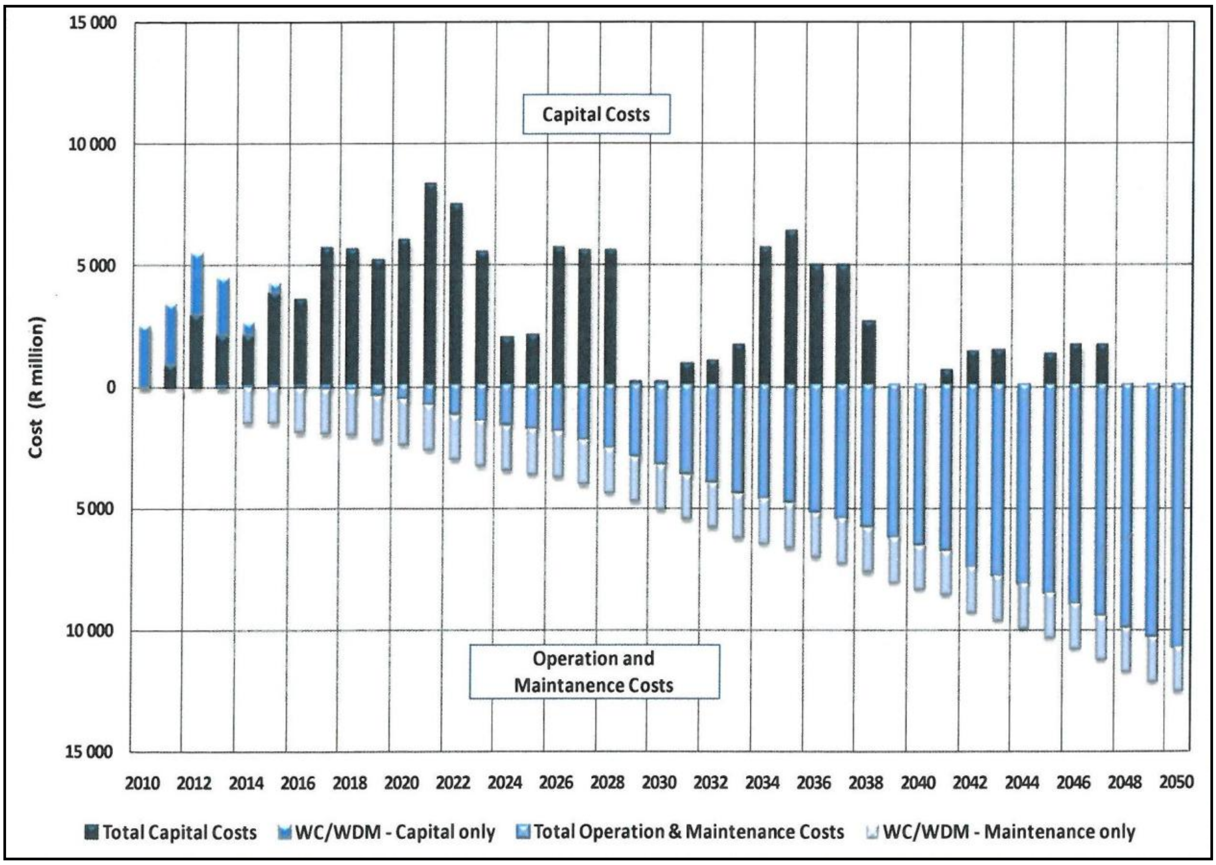

Figure 7-1: Projected future costs of water supply

7.7 Conclusion

The research led to an expanded and improved appraisal method called the Comprehensive Approach. The elements and linkages of this approach are schematically depicted in Figure 7-2. As can be seen by comparing these to the depiction of the Incremental Approach at the start of the study in Figure 1-1, this new approach has widened the scope of appraisal to include the uncertainties produced by the stochasticity of the hydrological inputs regarding variable costs. In addition the issue of effectiveness was brought to the fore in the URV measure; a differentiation was made between the water transfers that are likely to occur during the life of an IBT and the assurance of water supplies sought from the proposed project.

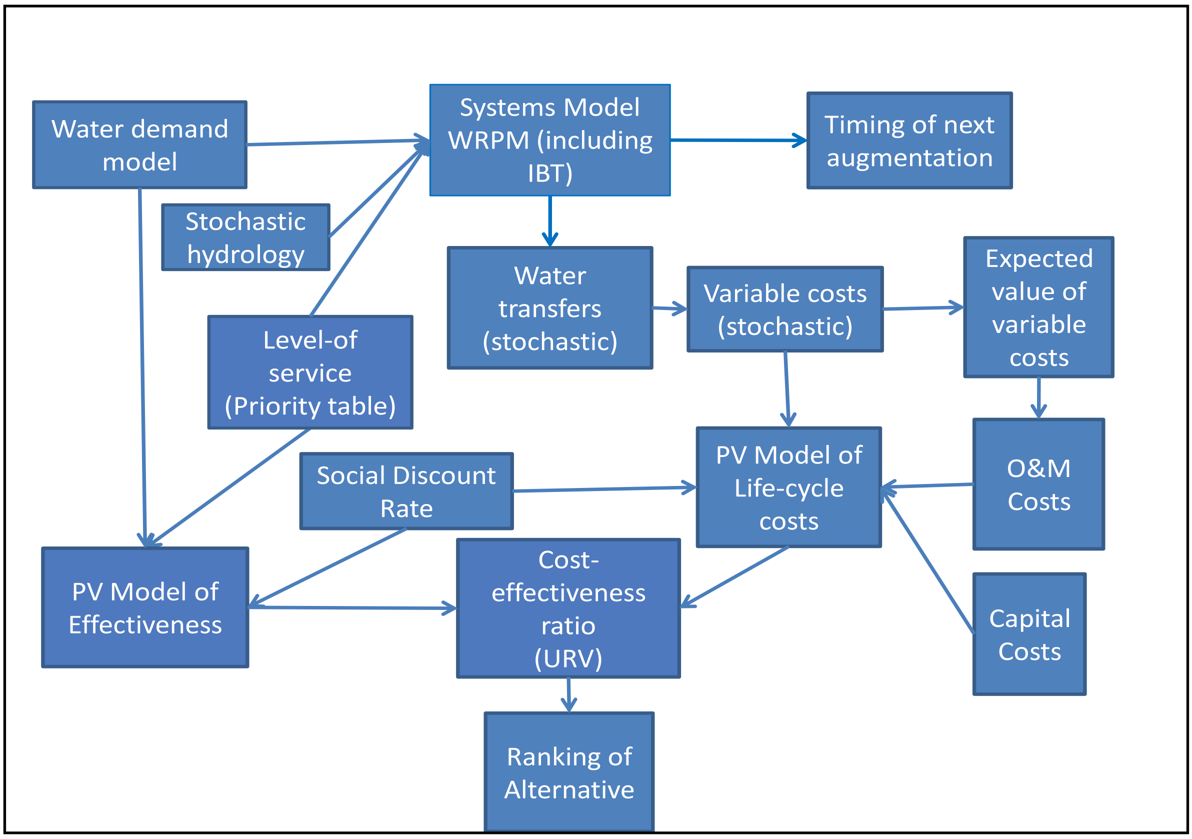

Figure 7-2: Complete schematic of the elements of the Comprehensive Approach

The new insights from this research will place water resource planning practitioners in a better position to recommend appropriate capacity expansion projects in future. While this study was limited in scope only to IBT projects, the same insights can also be transferred to other related schemes, such as sea-water desalination projects, emphasising the relevance and timeliness of this research.

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ANNEXURES

(Note that Annexures are numbered according to Chapter numbers, i.e. Annexure 4-A is the first annexure of Chapter 4.)

ANNEXURE 4-A

COMPARING ACTUAL WATER TRANSFERS (COMBINED) AGAINST DEMAND IN EXCESS OF GROOTDRAAI DAM YIELD (INCREMENTAL APPROACH)

Hydrological Year	Actual total water requirements from Grootdraai Dam (million m^3/a)	Transfers to meet demands in excess of yield of dam (2001 est.) (million m^3/a)	Actual transfers from Heyshope and Zaaihoek combined (million m^3/a)
1985/1986	142.36	18.36	64.4
1986/1987	140.23	16.23	51
1987/1988	146.63	22.63	13.8
1988/1989	158.72	34.72	0.1
1989/1990	163.61	39.61	0
1990/1991	162.62	38.62	0
1991/1992	185.77	61.77	45.1
1992/1993	173.33	49.33	140.3
1993/1994	186.96	62.96	122.1
1994/1995	202.01	78.01	161.23
1995/1996	181.03	57.03	22.14
1996/1997	162.30	38.30	0.05
1997/1998	182.66	58.66	40.07
1998/1999	183.91	59.91	58.45
1999/2000	165.70	41.70	15.07
2000/2001	173.76	49.76	17.09
2001/2002	177.46	53.46	21.11
2002/2003	199.62	75.62	79.45
2003/2004	242.86	118.86	78.44
2004/2005	212.06	88.06	43.14
2005/2006	214.60	90.60	28.05
2006/2007	223.98	99.98	29.74
2007/2008	213.98	89.98	16.83
2008/2009	241.89	117.89	14.37
2009/2010	197.29	73.29	1.12
Total (million m^3)		1535.36	1063.3
Average over 25 years of operation (million m^3/a)		61.41	42.53
Actual as percentage of Incremental Approach projection			69.25%

ANNEXURE 4-B

22 YEARS OF OPERATION OF THE INTEGRATED VAAL RIVER SYSTEM

		Year (starting 1 May and ending 30 April)						
		1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97
	Report No	PC 000/00/10090	PC 000/00/10491	PC 000/00/11192	PC 000/00/12593	PC 000/00/14994	PC 000/00/15695	PC 000/00/19596
	Reference in Annexure 4-C	1,2	3	4	5	6	7	8
1 May starting storage as % of Full Supply	Vaal Dam	96	87	39	16	51	16	100
	Sterkfontein	81	89	99	86	74	67	56
	Grootdraai	100	98	55	60	96	99	100
	Usutu	73	82	65	58	61	40	100
	Zaaihoek	81	100	91	49	59	27	100
	Heyshope	100	100	93	87	89	59	100
	Komati	96	97	59	37	65	51	100
Changes in configuration or capacity					New link completed between Usutu and Komati subsystems	Pumping problems at Geelhoutboom affect transfers from Zaaihoek	Pumping problems at Geelhoutboom continue to afect transfers	Katse Dam delivery starts 1 Jan 1997
Demand projections: basis and changes		TR134 (most probable) projection adjusted with RWB and Eskom projections	TR134 (most probable) projection adjusted with RWB and Eskom projections	TR134 (most probable) projection adjusted with RWB and Eskom projections	TR134 (most probable) projection adjusted with RWB and Eskom projections	TR134 (most probable) projection adjusted with RWB and Eskom projections	TR134 (most probable) projection adjusted with RWB and Eskom projections	Started from lower base due to restrictions in 1995
Demand scenario and short/med. term projection (million cub. m) g=gross, n=net		1990:2123g 1995:2715g 2000:3370g	1995:2688g 2000:3369g	1995:2724g 2000:3289g	1995:2728g 2000:3329g	2000:3468g	1995:2134g (with restrictions) 2000:3462g	2000: 2887g), 2477n 2005: 3499g, 2882n
General				Improved computer cap: from 210 up to 1000 stochastic sequences. Blending option improved.		Majuba Power Station starts to use water. Concern about delays with LHWP forced changes: Full pumping and restrictions from 1 April 95	Restrictions: Irrigation 40%, Municipal 20%, Mines & SASOL 10%, Eskom 5%. Exceptionally good rains from Nov 1996, restrictions lifted Jan 1997	
Combined Heyshope & Zaaihoek transfer to Grootdraai (million cub meters) prescribed in AOA		0		Pump full cap = 5+3 cumec = 252 million cub m/a (95% rule for Grootdraai Dam)	Pump full cap = 5+3 cumec = 252 million cub m/a (95% rule for Grootdraai Dam)	Pump full cap (4,5 cumec from Heyshope & 2,85 cumec from Zaaihoek) until end Sept 94 . After that 90% rule	Pump full cap (4,5 cumec from Heyshope & 2,85 cumec Zaaihoek) until end Sept . After that 90% rule	0
Actual transfers to Grootdraai Dam (million cubic meters)		0	16.4	141.1 Far less pumped due to pumping problems at Heyshope - less so at Zaaihoek	130.0 Less pumped due to initial pumping problems at Heyshope. More at Zaaihoek than projected. Grootdraai Dam full in Jan 1994 - due to transfers.	165.4	89.3 Stopped all transfers in Dec 1996 as Grootdraai > 90%	0
Thukela transfer to Sterkfontein Dam (cub meters/sec continuous) prescribed		5 cumec	11 cumec	11 cumec	20 cumec	20 cumec	20 cumec	20 cumec
Actual transfers to Sterkfontein Dam (million cubic meters)		no record	no record	no record	no record	no record	no record	no record
Actual releases from Sterkfontein Dam (million cubic meters)		0	0	1444.3	869.8	532.6	873.4	0

22 YEARS OF OPERATION OF THE INTEGRATED VAAL RIVER SYSTEM (cont'd)

		Year (starting 1 May and ending 30 April)						
		1997/98	1998/99	1999/2000	2000/1	2001/2	2002/3	2003/4
	Report No		PC 000/00/19998		PC 000/00/21800	PC 000/00/22201	PC 000/00/22602	P RSA C000/00/0204
	Reference in Annexure 4-C	9	10	11	12	13	14	15
1 May starting storage as % of Full Supply	Vaal Dam		98.3		97	92.7	95.9	68.9
	Sterkfontein		90.4			90.4	99.6	100
	Grootdraai		94.7		100	88.8	93.3	91.3
	Usutu		91		99	97.2	89.7	87.8
	Zaaihoek		99.5			99.5	99	77.7
	Heyshope		100			100	100	91.4
	Komati		95		100	92.7	73.8	69.2
Changes in configuration or capacity		Katse dam completed Feb 1998			Matsoko Diversion (LHWP) completed Jan 2001		Maguga Dam completed (no further releases to lower Komati irrigators)	Mohale Dam completed March 2004
Demand projections: basis and changes			March 1997 projections based on 1996 consumption and TR134 growth rates. Excludes diffuse irrigation and afforestation.		Vaal River Systems Analysis Update report as basis plus Rand Water, Eskom, SASOL, Mittal annual update	NWRS projections replaced VRSAU (significantly lower)		
Demand scenario and short/med. term projection (million cub. m) g=gross, n=net			1998: 2220n 2000: 2393n 2005: 2824n		2000: 3506g 2771n 2005: 3818g 2924n	2001:2328n 2005: 3151g 2467n	2002:3056g 2394n 2005:3180g 2497n	2003:3297g 2573n 2005:3391g 2650n 2010: 3559g 2800n
General								
Combined Heyshope & Zaaihoek transfer to Grootdraai (million cub meters) prescribed in AOA			Zaaihoek 90% and Heyshope 75% rule		No pumping unless Grootdraai< 75% FSL	No pumping unless Grootdraai< 75% FSL	No pumping unless Grootdraai< 75% FSL	No pumping unless Grootdraai< 75% FSL
Actual transfers to Grootdraai Dam (million cubic meters)		0	55.6 (all from Zaaihoek)	58.2	0	31.6	60.2 between Aug and Dec 02	76.3
Heyshope to Usutu SS								10
Actual transfer								12
Thukela transfer to Sterkfontein Dam (cub meters/sec continuous) prescribed			0		0	0	0	0
Actual transfers to Sterkfontein Dam (million cubic meters)		no record	no record	no record	no record	no record	no record	49
Actual releases from Sterkfontein Dam (million cubic meters)		0	0	0	0	0	0	0

22 YEARS OF OPERATION OF THE INTEGRATED VAAL RIVER SYSTEM (cont'd)

		Year (starting 1 May and ending 30 April)							
		2004/5	2005/6	2006/7	2007/8	2008/9	2009/10	2010/11	2011/12
	Report No	P RSA C000/00/0304	P RSA C000/00/2405	14/2/ C000/20/2	P RSA C000/00/7508	P RSA C000/00/7608	P RSA C000/00/11709	P RSA C000/00/14611	P RSA C000/00/15512
	Reference in Annexure 4-C	16	17	18	19, 21	20, 21	22	23	24
1 May starting storage as % of Full Supply	Vaal Dam	52	57.2	100	76.2	96.7	100	100.2	97
	Sterkfontein	99.8	100	100	98.2	99.9	99.6	99.2	100
	Grootdraai	96.5	99.4	100	86.7	98.6	96.4	100.9	97
	Usutu	60.5	75	99.5	77.3	64.6	83	98.5	94
	Zaaihoek	81.8	77.7	100	94.6	95.5	99.2	100	98
	Heyshope	94.3	98.8	100	99.6	100	100	100	100
	Komati	79.9	98.5	100	92.2	99.2	98.8	101.4	100
Changes in configuration or capacity			Morgenstond-Jericho link upgraded			VRESAP starts delivering water 1 Dec 2008	Vlakfontein canal refurbishment	Vlakfontein canal refurbishment	Vlakfontein canal refurbishment
Demand projections: basis and changes		Compensation release from Zaaihoek increased from 6.3 to 11.4 million cub m/a	Rand Water introduces a significantly higher scenario (tested but not used)		Reconciliation Strategy Scenario Report - (Base scenario used)	Scenarios: Base and High assumes unlawful irrig. use cont'd	Rand Water: High population without WC/DM (2.6% higher for 2010) Eskom Base same as 04, High up about 5% by 2013)	Assumed unlawful irrigation curbed by 2013	Assumed unlawful irrigation curbed by 2014 + Eskom reduction due to economic downturn
Demand scenario and short/med. term projection (million cub. m) g=gross, n=net		2004:3200g 2478n 2005:3217g 2496n 2010 3392g 2644n	2005:3213g 2492n 2010 3391g 2643n	2006:3281g 2587n 2010 3426g 2704n	2007:3711g 3017n 2010 3675g 2980n 2015: 3709g 2970n	Base 2010:2964n 2015:2988n	Base (A) 2010:3786g 3004n 2015:3861g 3099n	Base 2010:3078n 2015:3036n	Base 2011:3102n 2015:2972n
General				Lower Vaal and Middelburg / Witbank not included. 2006: 459g 313n 2010: 486g 328n (Total 2010: 3912g 3032n)	Demand figures include Lower Vaal and Middelburg / Witbank		Vlakfontein canal refurbishment pgm starts but problems with VRESAP operations	Vlakfontein canal refurbishment slower. VRESAP problems continue	Vlakfontein canal refurbishment slower. VRESAP problems continue
Combined Heyshope & Zaaihoek transfer to Grootdraai (million cub meters) prescribed in AOA		No pumping unless Grootdraai< 90% FSL	No pumping unless Grootdraai< 75% FSL	No pumping unless Grootdraai< 75% FSL	No pumping unless Grootdraai< 90% FSL Zaaihoek max 0.744 m3/s	ditto, 0.7 cumec max for Zaaihoek (max 140+22=162)	No pumping unless Grootdraai< 75% FSL	No pumping unless Grootdraai< 75% FSL	No pumping unless Grootdraai< 75% FSL
Actual transfers to Grootdraai Dam (million cubic meters)		85.2 (between Jul and Jan 05)	28.1 (between Oct and Jan 06)	0	32.8 (between Jun and Sep 09)	33.4 (between Aug and Jan 08)	4	0	0
Heyshope to Usutu SS		Transfer if Morgenstond less than 35 million cub m Target 44	44	Transfer if Morgenstond less than 35 million cub m 44max		Max 1.4 cub m/s if Morgenstond drops below 80 million cub m	Max 1.4 cub m/s if Morgenstond drops below 80 million cub m	Max 1.4 cub m/s if Morgenstond drops below 80 million cub m	Max 1.4 cub m/s if Morgenstond drops below 80 million cub m
Actual transfer		10.4	2	0	0	14.74	0	0	9.2
Thukela transfer to Sterkfontein Dam (cub meters/sec continuous) prescribed		0	0	0	0	0	0	0	0
Actual transfers to Sterkfontein Dam (million cubic meters)		80.3	0	0	0	0	0	0	0
Actual releases from Sterkfontein Dam (million cubic meters)		0	0	0	0	0	0	0	0

ANNEXURE 4-C

REFERENCES USED IN ANNEXURE 4-B

(Note the references are in chronological sequence and referenced by number.)

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ANNEXURE 4-D

INTEGRATED VAAL RIVER SYSTEM ANNUAL OPERATING ANALYSIS: VIEW OF DEMAND PROJECTIONS OVER TIME

	Demand Projection (million cubic meter)									
AOA reporting year	1990	1995	2000		2005		2010		2015	
	gross	gross	gross	net	gross	net	gross	net	gross	Net
1990/91	2123	2715	3370							
1991/92		2688	3369							
1992/93		2724	3289							
1993/94		2728	3329							
1994/94			3468							
1995/96		2134	3462							
1996/97			2887	2477	3499	2882				
1997/98										
1998/99				2393		2824				
1999/00										
2000/01			3506	2771	3818	3006				
2001/02					3151	2467				
2002/03					3180	2497				
2003/04					3391	2650	3559	2800		
2004/05					3217	2496	3392	2644		
2005/06					3213	2492	3391	2643		
2006/07							3426	2704		
2007/08							3675	2980	3709	2970
2008/09								2964		2988
2009/10							3786	3004	3861	3099
2010/11								3078		3036
2011/12										2972
Note: Net demand = gross demand minus return flows										

ANNEXURE 5-A

Mooi-Mgeni Transfer: PV calculation of pumping option – Intermittent Transfer (TCTA, 2009, Appendix C.4) (R'000)

	Pump station		Pipeline and break pressure tank	Maintenance			TOTAL EXCL ELECTRICITY	Pumping	Electricity
	Civil	M&E	Civil	P/S Civil	P/S M&E	Pipeline		Percentage	Cost
2011	12,755		81,180				93,935	0.00%	0
2012	12,755	70,050	81,180				163,985	0.00%	0
2013				64	2,802	812	3,678	98.60%	7,311
2014				64	2,802	812	3,678	98.60%	7,311
2015				64	2,802	812	3,678	98.60%	7,311
2016				64	2,802	812	3,678	98.60%	7,311
2017				64	2,802	812	3,678	98.60%	7,311
2018				64	2,802	812	3,678	98.60%	7,311
2019				64	2,802	812	3,678	23.10%	1,713
2020				64	2,802	812	3,678	24.90%	1,846
2021				64	2,802	812	3,678	26.70%	1,980
2022				64	2,802	812	3,678	28.50%	2,113
2023				64	2,802	812	3,678	30.30%	2,247
2024				64	2,802	812	3,678	33.60%	2,491
2025				64	2,802	812	3,678	40.60%	3,010
2026				64	2,802	812	3,678	47.60%	3,529
2027				64	2,802	812	3,678	53.60%	3,974
2028				64	2,802	812	3,678	59.60%	4,419
2029				64	2,802	812	3,678	66.60%	4,938
2030				64	2,802	812	3,678	73.60%	5,457
2031				64	2,802	812	3,678	79.60%	5,902
2032				64	2,802	812	3,678	86.60%	6,421
2033				64	2,802	812	3,678	93.60%	6,940
2034				64	2,802	812	3,678	51.60%	3,826
2035				64	2,802	812	3,678	53.60%	3,974
2036				64	2,802	812	3,678	55.60%	4,123
2037				64	2,802	812	3,678	57.60%	4,271
2038				64	2,802	812	3,678	59.60%	4,419
2039				64	2,802	812	3,678	62.60%	4,642
2040				64	2,802	812	3,678	64.60%	4,790
2041				64	2,802	812	3,678	66.60%	4,938
2042		35,025		64	2,802	812	38,703	69.60%	5,161
2043				64	2,802	812	3,678	71.60%	5,309
2044				64	2,802	812	3,678	74.60%	5,531
2045				64	2,802	812	3,678	76.60%	5,680
2046				64	2,802	812	3,678	79.60%	5,902
2047				64	2,802	812	3,678	81.60%	6,050
2048				64	2,802	812	3,678	84.60%	6,273
2049				64	2,802	812	3,678	86.60%	6,421
2050				64	2,802	812	3,678	89.60%	6,644
2051				64	2,802	812	3,678	92.60%	6,866
2052				64	2,802	812	3,678	96.60%	7,163
2053				64	2,802	812	3,678	98.60%	7,311
2054				64	2,802	812	3,678	98.60%	7,311
2055				64	2,802	812	3,678	98.60%	7,311
2056				64	2,802	812	3,678	98.60%	7,311
2057				64	2,802	812	3,678	98.60%	7,311
2058				64	2,802	812	3,678	98.60%	7,311
2059				64	2,802	812	3,678	98.60%	7,311
2060				64	2,802	812	3,678	98.60%	7,311
2061				64	2,802	812	3,678	98.60%	7,311
2062		-11,675		64	2,802	812	-7,997	98.60%	7,311
TOTAL							**465,149**		**275,939**
PV 6%							**291,016**		**72,057**
PV 8%							**268,910**		**54,117**
PV 10%							**252,631**		**42,855**

ANNEXURE 5-B

Mooi-Mgeni Transfer: PV calculation of pumping option – Continuous Transfer (TCTA, 2009, Appendix C.5) (R'000)

	Pump station		Pipeline and break pressure tank	Maintenance			TOTAL EXCL ELECTIRICITY	Electricity	Electricity
	Civil	M&E	Civil	P/S Civil	P/S M&E	Pipeline		Percentage	Cost
2011	12755		81180				93935	0.00%	0
2012	12755	70,050	81180				163985	0.00%	0
2013				64	2,802	812	3677.575	100.00%	7,415
2014				64	2,802	812	3677.575	100.00%	7,415
2015				64	2,802	812	3677.575	100.00%	7,415
2016				64	2,802	812	3677.575	100.00%	7,415
2017				64	2,802	812	3677.575	100.00%	7,415
2018				64	2,802	812	3677.575	100.00%	7,415
2019				64	2,802	812	3677.575	100.00%	7,415
2020				64	2,802	812	3677.575	100.00%	7,415
2021				64	2,802	812	3677.575	100.00%	7,415
2022				64	2,802	812	3677.575	100.00%	7,415
2023				64	2,802	812	3677.575	100.00%	7,415
2024				64	2,802	812	3677.575	100.00%	7,415
2025				64	2,802	812	3677.575	100.00%	7,415
2026				64	2,802	812	3677.575	100.00%	7,415
2027				64	2,802	812	3677.575	100.00%	7,415
2028				64	2,802	812	3677.575	100.00%	7,415
2029				64	2,802	812	3677.575	100.00%	7,415
2030				64	2,802	812	3677.575	100.00%	7,415
2031				64	2,802	812	3677.575	100.00%	7,415
2032				64	2,802	812	3677.575	100.00%	7,415
2033				64	2,802	812	3677.575	100.00%	7,415
2034				64	2,802	812	3677.575	100.00%	7,415
2035				64	2,802	812	3677.575	100.00%	7,415
2036				64	2,802	812	3677.575	100.00%	7,415
2037				64	2,802	812	3677.575	100.00%	7,415
2038				64	2,802	812	3677.575	100.00%	7,415
2039				64	2,802	812	3677.575	100.00%	7,415
2040				64	2,802	812	3677.575	100.00%	7,415
2041				64	2,802	812	3677.575	100.00%	7,415
2042		35,025		64	2,802	812	38702.58	100.00%	7,415
2043				64	2,802	812	3677.575	100.00%	7,415
2044				64	2,802	812	3677.575	100.00%	7,415
2045				64	2,802	812	3677.575	100.00%	7,415
2046				64	2,802	812	3677.575	100.00%	7,415
2047				64	2,802	812	3677.575	100.00%	7,415
2048				64	2,802	812	3677.575	100.00%	7,415
2049				64	2,802	812	3677.575	100.00%	7,415
2050				64	2,802	812	3677.575	100.00%	7,415
2051				64	2,802	812	3677.575	100.00%	7,415
2052				64	2,802	812	3677.575	100.00%	7,415
2053				64	2,802	812	3677.575	100.00%	7,415
2054				64	2,802	812	3677.575	100.00%	7,415
2055				64	2,802	812	3677.575	100.00%	7,415
2056				64	2,802	812	3677.575	100.00%	7,415
2057				64	2,802	812	3677.575	100.00%	7,415
2058				64	2,802	812	3677.575	100.00%	7,415
2059				64	2,802	812	3677.575	100.00%	7,415
2060				64	2,802	812	3677.575	100.00%	7,415
2061				64	2,802	812	3677.575	100.00%	7,415
2062		-11675		64	2,802	812	-7997.43	100.00%	7,415
TOTAL							465,149		370,736
PV 6%							291,016		104,014
PV 8%							268,910		77,767
PV 10%							252,631		60,757

ANNEXURE 5-C

Mooi-Mgeni Transfer: PV calculation tunnel option (TCTA, 2009, Appendix C.6) (R'000)

	Tunnel and intake	Gravity main and outfall	Maintenance	TOTAL
	Civil	Civil	Civil	
2011	174,125	21,200		195,325
2012	174,125	21,200		195,325
2013			1,953	1,953
2014			1,953	1,953
2015			1,953	1,953
2016			1,953	1,953
2017			1,953	1,953
2018			1,953	1,953
2019			1,953	1,953
2020			1,953	1,953
2021			1,953	1,953
2022			1,953	1,953
2023			1,953	1,953
2024			1,953	1,953
2025			1,953	1,953
2026			1,953	1,953
2027			1,953	1,953
2028			1,953	1,953
2029			1,953	1,953
2030			1,953	1,953
2031			1,953	1,953
2032			1,953	1,953
2033			1,953	1,953
2034			1,953	1,953
2035			1,953	1,953
2036			1,953	1,953
2037			1,953	1,953
2038			1,953	1,953
2039			1,953	1,953
2040			1,953	1,953
2041			1,953	1,953
2042			1,953	1,953
2043			1,953	1,953
2044			1,953	1,953
2045			1,953	1,953
2046			1,953	1,953
2047			1,953	1,953
2048			1,953	1,953
2049			1,953	1,953
2050			1,953	1,953
2051			1,953	1,953
2052			1,953	1,953
2053			1,953	1,953
2054			1,953	1,953
2055			1,953	1,953
2056			1,953	1,953
2057			1,953	1,953
2058			1,953	1,953
2059			1,953	1,953
2060			1,953	1,953
2061			1,953	1,953
2062			1,953	1,953
TOTAL				488,313
PV 6%				385,508
PV 8%				368,802
PV 10%				354,999

ANNEXURE 5-D

Mkomazi-Mgeni Transfer: Smithfield Dam to Baynesfield Augmentation

DISCOUNT RATE	PRESENT WORTH OF COSTS @ R1,00 / m3	NPV OF WATER DELIVERED	UNIT REFERENCE VALUE (cents/m3)
6%	1 607 230	2 160	74
8%	1 306 412	1 284	102
10%	1 080 655	799	135

MKOMAZI-MGENI TRANSFER STUDY

SCHEME 2C

YEAR	NET PRESENT COST (1994) AT 6%			NET PRESENT COST (1994) AT 8%			NET PRESENT COST (1994) AT 10%		
	CAPITAL	MAINTENANCE & OPERATION	ELECTRICITY	CAPITAL	MAINTENANCE & OPERATION	ELECTRICITY	CAPITAL	MAINTENANCE & OPERATION	ELECTRICITY
SHADOW									
1998	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0
2001	11 986	0	0	11 332	0	0	10 725	0	0
2002	22 505	0	0	20 884	0	0	19 406	0	0
2003	165 626	26	0	150 848	24	0	137 624	22	0
2004	79 101	24	0	70 709	22	0	63 338	20	0
2005	191 682	23	0	168 173	20	0	147 902	18	0
2006	247 750	22	0	213 339	19	0	184 212	16	0
2007	262 214	21	0	221 613	17	0	187 877	15	0
2008	0	3 797	503	0	3 150	418	0	2 622	348
2009	5 398	3 582	702	4 395	2 917	572	3 592	2 384	467
2010	11 656	3 380	884	9 314	2 701	706	7 473	2 167	567
2011	68 682	3 204	1 052	53 865	2 512	825	42 434	1 979	650
2012	49 153	3 022	1 205	37 836	2 326	928	29 264	1 799	718
2013	128 099	2 851	1 346	96 778	2 154	1 017	73 493	1 636	773
2014	146 654	2 690	1 475	108 744	1 994	1 094	81 078	1 487	815
2015	24 909	5 193	1 592	18 128	3 779	1 159	13 270	2 766	848
2016	23 499	4 899	1 699	16 785	3 499	1 214	12 064	2 515	872
2017	0	4 836	1 799	0	3 391	1 261	0	2 393	890
2018	0	4 563	1 889	0	3 140	1 300	0	2 175	900
2019	0	4 304	1 970	0	2 907	1 330	0	1 977	905
2020	0	4 061	2 042	0	2 692	1 354	0	1 798	904
2021	0	3 831	2 107	0	2 492	1 371	0	1 634	899
2022	0	4 828	2 164	0	3 083	1 382	0	1 985	890
2023	0	3 410	2 215	0	2 137	1 388	0	1 351	877
2024	0	3 217	2 181	0	1 978	1 341	0	1 228	832
2025	0	3 034	2 057	0	1 832	1 242	0	1 116	757
2026	0	2 863	1 941	0	1 696	1 150	0	1 015	688
2027	0	2 701	1 831	0	1 571	1 065	0	922	625
2028	0	2 548	1 727	0	1 454	986	0	839	569
2029	0	2 899	1 629	0	1 624	913	0	920	517
2030	0	2 268	1 537	0	1 247	845	0	693	470
2031	0	2 139	1 450	0	1 154	783	0	630	427
2032	0	2 018	1 368	0	1 069	725	0	573	388
2033	0	1 904	1 291	0	990	671	0	521	353
2034	0	1 796	1 218	0	916	621	0	473	321
2035	0	1 694	1 149	0	849	575	0	430	292
2036	0	1 599	1 084	0	786	533	0	391	265
2037	0	2 014	1 022	0	972	493	0	475	241
2038	0	1 423	964	0	674	457	0	323	219
2039	0	1 342	910	0	624	423	0	294	199
2040	0	1 266	858	0	577	391	0	267	181
2041	0	1 195	810	0	535	362	0	243	165
2042	0	1 127	764	0	495	336	0	221	150
2043	0	1 063	721	0	458	311	0	201	136
2044	0	1 210	680	0	512	288	0	220	124
2045	0	946	641	0	393	266	0	166	112
2046	0	893	605	0	364	247	0	151	102
2047	0	842	571	0	337	228	0	137	93
2048	0	794	539	0	312	212	0	125	85
2049	0	749	508	0	289	196	0	113	77
2050	0	707	479	0	267	181	0	103	70
2051	0	667	452	0	248	168	0	94	63
2052	0	841	427	0	306	155	0	114	58
2053	0	594	402	0	212	144	0	77	52
RES+2053	0	560	380	0	197	133	0	70	48
TOTAL	1 438 913	111 477	56 840	1 202 743	69 912	33 757	1 013 752	45 902	21 001

ANNEXURE 5-E

MCWAP Scenario 8: Net water requirements from Phases 1 and 2

Year	Total water requirement (million m^3/a)	Net water supply from Mokolo Dam (million m^3/a)	Net water supply from Vlieëpoort on the Crocodile River (million m^3/a)
		Phase 1	Phase 2
2008	12.13	12.13	0.00
2009	13.75	13.75	0.00
2010	14.60	14.60	0.00
2011	20.25	20.25	0.00
2012	28.03	28.03	0.00
2013	39.63	39.63	0.00
2014	50.40	36.41	13.99
2015	72.07	27.40	44.67
2016	110.02	28.70	81.32
2017	128.58	28.70	99.88
2018	133.36	28.70	104.66
2019	146.22	28.70	117.52
2020	155.93	28.70	127.23
2021	164.38	28.70	135.68
2022	190.96	28.70	162.26
2023	207.14	28.70	178.44
2024	211.84	28.70	183.14
2025	216.70	28.70	188.00
2026	218.77	28.70	190.07
2027	219.00	28.70	190.30
2028	219.23	28.70	190.53
2029	219.58	28.70	190.88
2030	219.95	28.70	191.25
2035	219.95	28.70	191.25
2040	219.95	28.70	191.25
2060	219.95	28.70	191.25

ANNEXURE 5-F

MCWAP 2: Electricity costs of transferring water from the Crocodile River

Year	Electricity Cost	
	Before escalation	After escalation
2014	4.57	11.37
2015	9.61	23.90
2016	15.62	38.87
2017	18.32	45.58
2018	19.05	47.41
2019	21.02	52.31
2020	22.51	56.02
2021	23.81	59.24
2022	27.74	69.02
2023	30.13	74.98
2024	30.83	76.71
2025	31.55	78.50
2026	31.85	79.26
2027	31.89	79.34
2028	31.92	79.43
2029	31.97	79.56
2030	32.03	79.69
2031	32.03	79.69
2032	32.03	79.69
2033	32.03	79.69
2034	32.03	79.69
2035	32.03	79.69
2040	32.03	79.69
2045	32.03	79.69
2050	32.03	79.69
2055	32.03	79.69
2060	32.03	79.69

ANNEXURE 5-G

Thukela Vaal: Projected annual transfers

Year	Vaal River system demand	Vaal River system yield	Augmentation from TWP
	million m^3/a	million m^3/a	million m^3/a
2007	2952	2877	0.0
2008	2996	2877	0.0
2009	2946	2877	0.0
2010	2889	2877	0.0
2011	2827	2877	0.0
2012	2831	2877	0.0
2013	2859	2877	0.0
2014	2889	2877	0.0
2015	2920	2877	0.0
2016	2940	2877	0.0
2017	2964	2877	0.0
2018	2988	2877	0.0
2019	3013	2877	135.8
2020	3037	2877	160.4
2021	3051	2877	174.0
2022	3065	2877	188.3
2023	3080	2877	202.7
2024	3096	2877	218.7
2025	3109	2877	232.5
2026	3127	2877	250.3
2027	3146	2877	268.5
2028	3164	2877	287.0
2029	3183	2877	305.9
2030	3204	2877	326.7
2031	3223	2877	346.1
2032	3243	2877	365.7
2033	3262	2877	385.3
2034	3282	2877	396.0
2035	3302	2877	396.0
2036	3322	2877	396.0
2037	3342	2877	396.0
2038	3362	2877	396.0
2039	3383	2877	396.0
2040	3403	2877	396.0

ANNEXURE 5-H

Thukela-Vaal: Projected annual electricity costs

Year	Electricity Cost (R million)
2019	76 881
2020	90 807
2021	98 487
2022	106 579
2023	114 737
2024	123 794
2025	131 571
2026	141 690
2027	151 972
2028	162 420
2029	173 168
2030	184 920
2031	195 913
2032	206 973
2033	218 100
2034	224 136
2035	224 136
2040	224 136
2045	224 136
2050	224 136
2058	224 136

ANNEXURE 5-I

Wanjiazhai Water Transfer Project Phase 1: Economic analysis (million 1996 Yuan)
(World Bank, 1997:186)

			Project life:	50	years	Losses:	
IERR=	22.0%		exchange rate on costs:	8.3		Gen Main	3%
B/C=	1.7		operating costs (2002):	1.22	Y/m3	South I	2%
			treatment costs (2002):	0.83	Y/m3	South II	2%
discounted benefits=	25,191	million Y	opportunity costs (2002):	0.60	Y/m3		
discounted total costs =	14,783	"	waste treat costs (2002):	0.60	Y/m3	Delivery eff.	93%
net present value=	10,408					Treatment eff.	91%
discount rate=	12%						

										1		$25,191	
									0.06659707	0.8331364	0.10026653		
	9,665	4.74489058	2037		7.2573102		1	$14,783.37	$1,678	$20,988	$2,526	$25,191	$10,408
		0%	Water	Operating	Treatment	Opportunity	Wastewater	Total	Houshold	Industry	Irrigation	Gross	net
	Costs	contingency	diverted	costs	costs	costs	costs	costs	benefits	benefits	benefits	benefits	benefits
1996	2241	-	-	-	-	-	-	2,241	-	-	-	-	-2,241
1997	1532	-	-	-	-	-	-	1,532	-	-	-	-	-1,532
1998	2632	-	-	-	-	-	-	2,632	-	-	-	-	-2,632
1999	2608	-	-	-	-	-	-	2,608	-	-	-	-	-2,608
2000	1888	-	-	-	-	-	-	1,888	-	-	-	-	-1,888
2001	1083	-	-	-	-	-	-	1,083	-	-	-	-	-1,083
2002	226	-	269	328	208	161	82	1,005	176	4,961	460	5,598	4,593
2003	348	-	304	371	230	182	90	1,221	205	5,166	483	5,854	4,633
2004	338	-	341	409	258	205	101	1,311	234	5,339	507	6,080	4,769
2005	696	-	379	451	286	227	109	1,769	267	5,519	532	6,318	4,548
2006	274	-	420	487	317	252	119	1,450	302	5,636	559	6,496	5,046
2007	68	-	464	534	350	278	131	1,361	341	5,765	587	6,694	5,332
2008	68	-	510	571	385	306	142	1,472	383	5,891	617	6,890	5,418
2009	136	-	559	620	422	335	155	1,668	434	5,968	649	7,052	5,383
2010	136	-	610	665	461	366	168	1,795	496	6,026	682	7,205	5,410
2011			640	685	483	384	176	1,728	529	5,915	702	7,146	5,418
2012			640	678	483	384	169	1,714	542	5,518	702	6,762	5,048
2013			640	672	483	384	169	1,708	554	5,161	702	6,417	4,709
2014			640	666	483	384	169	1,702	567	4,843	702	6,112	4,410
2015	1228		640	666	483	384	162	2,924	580	4,566	702	5,847	2,924
2016			640	666	483	384	162	1,695	593	4,288	702	5,582	3,887
2017			640	666	483	384	175	1,708	608	4,049	702	5,359	3,650
2018			640	666	483	384	166	1,699	621	3,811	702	5,134	3,434
2019			640	666	483	384	166	1,699	635	3,613	702	4,950	3,250
2020			640	666	483	384	192	1,699	650	3,414	702	4,766	3,066
2021			640	666	483	384	-	1,533	650	3,255	702	4,607	3,074
2022			640	666	483	384	-	1,533	650	3,097	702	4,448	2,915
2023			640	666	483	384	-	1,533	650	2,938	702	4,289	2,756
2024			640	666	483	384	-	1,533	650	2,819	702	4,170	2,637
2025			640	666	483	384	-	1,533	650	2,700	702	4,051	2,518
2026			640	666	483	384	-	1,533	650	2,581	702	3,932	2,399
2027			640	666	483	384	-	1,533	650	2,461	702	3,813	2,280
2028			640	666	483	384	-	1,533	650	2,382	702	3,733	2,200
2029			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2030	1228		640	666	483	384	-	2,761	650	2,303	702	3,654	893
2031			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2032			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2033			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2034			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2035			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2036			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2037			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2038			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2039			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2040			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2041			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2042			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2043			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2044	1228		640	666	483	384	-	2,761	650	2,303	702	3,654	893
2045			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2046			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2047			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2048			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2049			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2050			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121
2051			640	666	483	384	-	1,533	650	2,303	702	3,654	2,121

ANNEXURE 5-J

SEQ: Failure in correct assessment of yield assurance level

The Government of Queensland, in their report *Water for South East Queensland – A Long Term Solution,* deliberated appropriate level-of-service (LOS) criteria. Regarding the frequency of water restrictions it was decided that a suitable LOS would be supplying water at a 1:50 year average recurrence interval (ARI) assurance level (Queensland Government, 2006:45-46).

Stochastic hydrological runs were undertaken to determine yields that reflect probabilities of failures. This was done for the existing Wivenhoe-Somerset Dam systems, the main supply to the city of Brisbane and surrounds. Two sets of runs of 100 years in length, one consisting of 98 runs and the other of 500 runs, were generated "with similar statistical characteristics to that of the historical record" (Queensland Government, 2006:45).

The so-called "no-failure" yields of each of these runs were plotted as shown in Figure A-1 (2006:46). (Note that the yield distribution graph is identical to the "long-term firm yield line" concept used in South Africa, as described in Basson, et al. (1994:41)). From the graph the 1:50 year (or 95% assured) LOS yield for the system was derived as being "about 285 000 ML/annum", i.e. 285 million m^3/a. The 1:100, or 99% assured, yield was estimated at 260 million m^3/a. These yields were considerably lower than the so-called historic no-failure yield (HNFY) of 373 million m^3/a – also shown in Figure A-1.

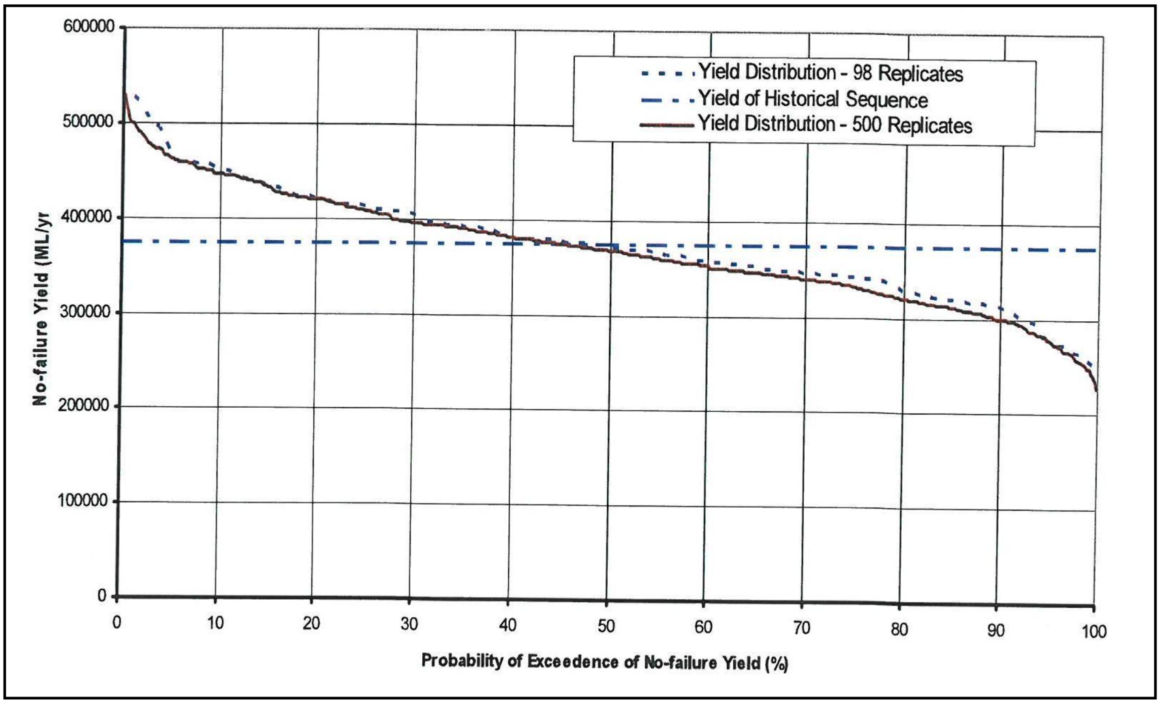

Figure A-1: Wivenhoe-Somerset System no-failure yield distribution

The *Long Term Solution* report described how the HNFY needed "de-rating" to meet the LOS yield criterion (Queensland Government, 2006:45). This de-rating was applied to the rest of the resources supplying the South East Queensland (SEQ) Region. These re-rated yields were termed "prudent yields". Whereas the total HNFY for the system was determined as 630 million m^3/a, the "prudent yield" was established as 450 million m^3/a. The latter figure was used as basis to establish the long term strategy for the SEQ region (2006:49).

Unfortunately a fundamental error occurred in the mathematical derivation of the 1 in 50 year yield (and also the 1 in 100 year yield) in the *Long Term Solution* Report. This requires some explanation:

A recurrence interval T has a probability R=1/T of occurring in any year – this is the annual risk of failure. The risk of failure during an n year flow sequence, the planning period, is calculated as the long-term risk of failure, $R_n = 1-(1-1/T)^n$. This is the well-known Bernoulli relationship (Basson et al., 1994:31). What is depicted in the axis, "Probability of exceedence of no-failure Yield (%)", in Figure A-1, is the long term reliability of ($1-R_n$) and not the annual reliability (1-R). The 1 in 100 year ARI (average recurrence interval) in this case would be where $1-R_n$ is 36.7%, i.e. the 1 in 100 year yield of this sub-system is about 390 million m^3/a, and not the 260 million m^3/a as stated. Similarly the 1 in 50 year ARI occurs where the $1-R_n$ is 13,3%, i.e. the 1 in 50 year yield is about 440 million m^3/a.

Reading off the graph the HNFY has a long term reliability of 46%, therefore an annual reliability of 99.2% or a 1 in 125 year assurance (ARI). The LOS yield, thought to have an ARI of 1 in 50 years, in fact had an ARI of 1 in 5000 years. (Note that the hydrology used in 2006 could not have included the latest "Millennium" drought climatic data and therefore it can be expected that an updated hydrology would indicate lower yields for the system than the corrected ones above.)

There is no indication that the error pointed out here was rectified in subsequent years, but a number of reports did query the "re-rating" of the HNFY. A review commissioned by the Mary River Council of Mayors, representing a community of half a million people with concern about the proposed Traveston Crossing Dam (TCD) scheme, expressed its unease about the de-rating (which it called a "downgrading") of the yield, and stated that the LOS criteria should have been tested through "customer surveys, community engagement processes or other empirical analysis ... to set the LOS" (Turner et al., 2007:18-19). The report suggested investigating a 1 in 25 year ARI as a "slight increase in the probability of restrictions is likely to significantly increase the prudent yield, which will reduce the supply-demand gap".

Increasingly throughout the report they refer to the LOS assumptions and the prudent yield as being “conservative” and “extremely conservative” (2007:32).

In a review of the economic aspects of the Traveston Crossing Dam Environmental Impact Assessment documentation for the Department of Environment, Water, Heritage and the Arts of the Commonwealth Government the cost-benefit analysis of Marsden Jacobs Associates (2007a) is criticised for not considering “the communities’ tolerance for higher levels of risk” (Centre for International Economics, 2009:34), also indicating a discomfort with the LOS criterion.

The Queensland Water Commission seemingly came to the subsequent conclusion that the LOS was indeed conservative. Its *South East Queensland Strategy* of 2010 (issued after the drought had broken) mentioned that the revised LOS objective meant that “the community can expect to experience water restrictions no more than once every 25 years, on average”. Establishing the LOS “involved trade-offs between financial costs, environmental impacts and the willingness of the community to accept restrictions on a periodic basis. Information gained from managing the Millennium Drought has been used in the formulation of the LOS objectives. The experience of managing regional water security during the Millennium Drought has provided useful evidence about practical issues and community expectations” (Queensland Water Commission, 2010:38-39). The 2010 South East Queensland Strategy envisaged that, by 2011, the LOS system yield would reach 525 million m^3/a, with the SEQ Water Grid, the Western Corridor Recycled Water Scheme, and the Tugun desalination plant operational, and the upgrade of the Hinze Dam and the construction of the Wyaralong Dam completed.

After vehement public opposition, and extensive investigations, the TCD was finally scrapped by the Minister for the Environment, Heritage and the Arts in November 2009. Environmental concerns, particularly for the endangered Queensland lungfish, endemic to the Mary River, as well as social concerns were the main reasons provided (Wasimi 2011:27). Conceivably the Queensland Government would have considered a different set of portfolios to meet the (reduced) shortfalls, had the yields been correctly assessed at the time and this may have meant that the TCD option would have been abandoned far earlier, with less expenditure of resources and fewer anxieties generated.

Postscript: The Wyaralong Dam was completed in December 2010, just as severe floods hit Queensland and the city of Brisbane. Thousands of people had to be evacuated; some 20000 homes were affected when the flood reached its peak on 14 January 2011. The

Wyaralong Dam, however, is credited with saving even more damage along the Logan River (Wikipedia, (n.d.) *2010-2011 Queensland Floods*).

ANNEXURE 5-K

SEQ augmentation: breakdown of costs of water supply options (2007 Aus$) (Marsden Jacobs Associates, 2007a:45)

Source Option	Annual Take ML/a	Capital Costs Source $M	Capital Costs Connection $M	Capital Costs Treatment $M	Capital Costs Total $M	Source Fixed $M/a	Source Variable $/ML	Connection Fixed $M/a	Connection Variable $/ML	Treatment Fixed $M/a	Treatment Variable $/ML	Total Fixed $M/a	Total Variable $/ML	Total Annual $M/a
Wyaralong	18,000	285	21	27	333	0.5	0	1.1	0	10.4	265	12.1	265	16.8
Cedar Crove Weir + BOSS	8,000	68	10	13	90	0.0	0	0.5	0	2.5	240	3.0	240	4.9
Traveston Stage 1	70,000	1,325	137	130	1,592	1.1	0	7.4	57	9.6	150	18.1	207	32.6
Borumba	40,000	632	0	0	632	0.5	0	0.0	57	5.5	210	6.0	267	16.7
Traveston Stage 2	40,000	382	60	75	517	0.0	0	6.4	19	5.5	210	11.9	229	21.0
Glendower	18,900	657	100	50	807	0.5	0	5.4	0	3.9	240	9.8	240	14.3
Raised Wappa	16,450	349	10	46	405	0.3	0	0.5	57	3.4	245	4.2	302	9.2
Cambroon	39,200	604	178	82	864	0.5	0	9.6	57	5.4	210	15.5	267	25.9
Amamoor	14,560	318	126	43	487	0.3	0	6.8	57	4.0	250	11.1	307	15.5
Borumba + Coles Crossing	26,600	719	68	65	852	0.5	0	7.4	57	5.5	230	13.3	287	21.0
Tweed River TW7	12,000	387	167	67	621	0.8	0	3.0	205	2.5	240	6.2	445	11.6
Clarence MA1	20,000	380	1,505	133	2,018	0.2	0	17.6	249	4.1	254	21.9	503	31.9
Clarence CL3b	70,000	1,031	772	133	1,936	3.4	0	9.9	225	9.6	150	22.8	375	49.0
Desal 1st 120 ML/d	43,800	973	218	0	1,192	26.0	348	4.1	38	0.0	0	30.1	386	47.1
Desal 2nd 120 ML/d Increment	43,800	418	0	0	418	11.8	348	1.0	38	0.0	0	12.8	386	29.7
Desal 240 ML/d Increment	87,600	1,276	218	0	1,494	34.9	348	4.5	38	0.0	0	39.4	386	73.3

ANNEXURE 6-A

PVs of 995 sequences of stochastic water transfers used in TWP analysis (base date 2010)

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
1	441.4	256.5	154.2
2	138.3	72.2	38.7
3	340.2	202.5	124.4
4	341.2	196.8	116.1
5	403.4	234.7	140.3
6	311.0	192.3	122.2
7	105.9	58.1	33.7
8	623.3	333.1	180.9
9	166.6	93.6	53.9
10	179.5	91.4	47.3
11	341.3	170.3	86.4
12	180.0	89.0	44.7
13	637.5	357.2	203.6
14	352.7	186.3	100.7
15	354.4	212.1	129.9
16	550.9	297.7	163.2
17	306.5	169.2	94.6
18	207.0	101.5	50.6
19	145.7	84.7	50.5
20	390.6	219.1	124.7
21	148.8	81.2	45.4
22	105.9	50.1	24.1
23	465.3	237.3	122.9
24	276.9	145.6	78.2
25	259.9	130.4	66.6
26	263.7	134.0	69.1
27	261.8	136.7	72.8
28	223.1	110.8	55.9
29	313.2	164.8	88.3
30	420.8	225.0	122.5
31	607.9	340.4	195.0
32	162.5	83.1	43.5
33	372.4	205.8	116.9

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
34	916.2	526.1	308.8
35	370.4	211.6	122.4
36	354.7	185.3	98.6
37	72.2	44.9	28.5
38	312.9	156.3	79.3
39	238.7	154.8	104.8
40	341.3	192.3	111.0
41	703.2	383.6	212.4
42	449.0	238.9	129.3
43	77.6	37.3	18.2
44	142.0	80.1	46.0
45	436.5	230.9	125.1
46	224.1	116.7	61.7
47	543.0	319.9	191.5
48	137.9	75.9	42.8
49	38.8	19.4	9.8
50	240.7	119.4	60.2
51	849.1	508.6	310.1
52	34.6	16.8	8.3
53	272.8	144.1	77.4
54	259.2	132.1	68.9
55	297.7	172.0	102.6
56	103.4	51.4	25.9
57	202.3	113.4	67.1
58	113.4	55.2	27.2
59	653.8	370.3	214.2
60	490.6	255.7	135.3
61	254.8	126.0	63.5
62	279.6	142.2	73.8
63	370.4	201.8	112.1
64	330.0	171.1	90.0
65	124.1	64.4	34.0
66	349.7	200.1	116.6

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
67	441.4	253.2	148.3
68	301.7	188.1	122.5
69	358.4	177.8	89.5
70	480.1	273.8	159.7
71	188.8	98.5	52.4
72	383.5	207.6	117.4
73	325.2	193.5	117.0
74	197.6	106.0	57.7
75	198.5	109.7	61.9
76	68.7	33.9	17.0
77	691.7	393.0	227.6
78	345.2	187.6	103.6
79	293.2	157.8	86.4
80	64.5	32.3	16.5
81	534.9	288.1	158.3
82	157.4	85.6	47.8
83	562.6	317.5	183.9
84	65.1	31.4	15.4
85	324.8	205.6	132.8
86	324.4	179.7	101.6
87	506.2	278.4	156.1
88	269.6	161.0	100.7
89	144.2	73.0	37.6
90	559.3	363.5	245.1
91	293.3	166.0	97.2
92	116.4	62.4	34.0
93	90.1	43.1	20.9
94	412.5	215.7	115.1
95	120.2	61.2	31.8
96	200.2	99.9	50.5
97	471.1	247.3	131.9
98	347.7	175.1	89.5
99	366.0	198.0	109.1
100	564.7	357.2	232.4
101	310.2	169.0	94.7
102	508.3	281.2	159.2
103	193.7	97.6	50.3

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
104	775.5	471.0	294.3
105	362.6	190.2	101.6
106	266.3	131.3	65.7
107	251.5	127.3	65.3
108	201.7	100.0	50.3
109	427.9	230.1	126.1
110	399.1	221.8	126.5
111	151.7	92.9	58.6
112	126.5	61.3	30.1
113	109.3	52.6	25.7
114	679.7	391.9	229.6
115	239.8	124.5	65.9
116	426.8	270.7	177.8
117	489.1	256.9	137.7
118	298.7	168.0	96.8
119	481.5	243.3	124.8
120	443.9	298.1	207.1
121	157.6	82.3	44.1
122	76.9	37.4	18.4
123	197.9	117.6	71.9
124	345.7	188.3	104.4
125	265.2	133.6	68.5
126	133.4	72.0	39.9
127	546.3	297.9	165.4
128	868.8	500.0	293.7
129	387.0	231.2	144.5
130	340.5	182.3	99.5
131	256.3	125.7	62.5
132	651.6	437.4	303.8
133	177.1	89.1	45.5
134	337.5	171.6	89.2
135	179.2	87.4	43.3
136	81.3	40.0	20.0
137	263.4	149.1	86.8
138	368.9	234.8	154.0
139	101.1	49.9	25.0
140	393.5	265.2	185.7

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
141	394.9	238.2	149.5
142	411.5	238.3	142.2
143	470.2	238.4	122.7
144	748.0	496.0	338.1
145	328.3	167.6	87.8
146	196.2	98.6	50.5
147	212.9	115.3	64.0
148	457.8	295.8	201.5
149	224.1	111.7	56.4
150	298.1	149.9	76.8
151	262.1	132.1	67.6
152	319.9	169.9	93.2
153	301.8	148.6	74.2
154	322.2	164.9	85.8
155	347.8	178.2	92.8
156	347.4	177.4	92.5
157	239.9	118.7	59.7
158	570.3	326.4	193.8
159	323.9	167.7	88.4
160	452.6	262.6	157.9
161	279.0	141.6	72.9
162	471.9	239.0	122.8
163	183.3	91.8	46.7
164	157.6	84.9	46.9
165	501.4	279.1	160.2
166	592.5	383.6	256.7
167	204.6	101.7	51.3
168	191.3	93.5	46.4
169	183.3	88.9	43.8
170	163.0	80.4	40.2
171	340.4	182.7	100.5
172	86.9	42.4	21.0
173	467.8	250.4	136.9
174	300.8	165.5	94.6
175	201.7	102.2	52.5
176	130.8	62.9	30.6
177	252.1	129.8	67.7

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
178	359.9	198.5	111.0
179	696.4	379.9	212.3
180	374.0	192.3	100.4
181	244.4	124.0	64.6
182	203.9	106.3	57.3
183	447.0	285.0	187.4
184	495.7	262.2	141.5
185	204.0	105.2	55.4
186	177.9	104.0	62.4
187	112.9	57.1	29.3
188	498.6	290.1	173.1
189	240.4	131.3	73.0
190	235.9	117.5	59.5
191	385.1	212.2	119.5
192	298.7	150.0	76.7
193	189.7	103.8	58.1
194	516.3	283.4	157.9
195	437.2	234.7	129.6
196	174.4	83.7	40.8
197	367.9	190.3	100.3
198	158.8	89.1	51.7
199	420.2	229.9	129.5
200	437.1	229.4	122.5
201	523.6	291.3	165.8
202	926.6	536.2	316.6
203	780.0	446.0	259.0
204	307.6	158.9	83.3
205	549.2	320.8	191.5
206	661.2	411.6	265.5
207	325.8	170.8	90.9
208	214.8	107.3	54.6
209	424.9	218.0	114.1
210	230.9	115.8	59.0
211	462.7	245.0	131.5
212	218.9	115.3	62.4
213	249.5	127.3	66.4
214	575.6	309.1	168.4

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
215	58.7	27.8	13.3
216	167.9	82.3	40.9
217	352.0	179.7	93.5
218	768.8	502.7	339.0
219	222.1	129.7	80.3
220	705.8	369.3	196.4
221	335.7	168.5	85.8
222	301.5	177.9	107.7
223	438.7	226.4	118.7
224	250.0	134.4	73.3
225	160.7	78.0	38.4
226	121.4	65.1	35.7
227	443.1	239.6	131.3
228	340.6	201.2	121.0
229	371.7	186.9	95.4
230	649.0	390.2	240.9
231	183.4	94.0	49.3
232	198.3	99.8	51.0
233	484.0	262.4	145.1
234	243.7	123.5	63.5
235	377.9	212.0	121.7
236	146.4	70.4	34.3
237	399.3	222.3	127.5
238	741.3	426.0	248.3
239	259.7	132.5	68.9
240	341.1	175.2	91.5
241	425.5	227.0	122.9
242	80.8	46.3	26.8
243	102.0	52.6	27.5
244	460.8	234.7	121.4
245	433.9	244.5	140.1
246	467.7	252.8	140.1
247	303.9	157.6	83.5
248	299.6	153.7	81.3
249	218.4	115.0	61.4
250	385.0	207.7	114.0
251	200.4	104.3	55.8

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
252	351.8	179.2	92.6
253	41.9	20.4	10.1
254	259.1	135.3	71.7
255	96.8	45.9	22.0
256	47.0	24.1	12.6
257	381.6	207.1	115.4
258	671.8	424.8	276.1
259	57.5	32.7	18.9
260	473.9	304.5	206.0
261	916.7	507.4	286.7
262	71.9	35.1	17.4
263	174.6	84.4	41.4
264	563.2	336.7	207.3
265	314.8	171.7	95.5
266	234.3	116.2	58.4
267	33.0	15.7	7.6
268	418.2	234.8	137.2
269	515.4	285.3	160.9
270	253.7	147.7	88.1
271	553.4	296.3	161.8
272	552.4	293.1	157.9
273	218.0	119.9	67.5
274	316.5	179.0	102.7
275	517.9	291.5	166.7
276	163.0	102.7	66.8
277	185.8	89.2	43.5
278	208.8	109.2	58.2
279	127.0	62.7	31.4
280	366.2	185.3	95.4
281	416.6	222.8	121.5
282	518.5	323.8	212.7
283	647.2	384.7	238.7
284	86.6	42.7	21.3
285	524.7	276.4	148.1
286	390.6	211.5	116.7
287	545.3	298.3	166.1
288	121.3	61.3	31.6

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
289	192.4	98.3	51.3
290	210.3	102.4	50.6
291	51.3	27.0	14.4
292	767.1	461.4	286.7
293	471.2	239.5	123.7
294	425.7	259.8	163.4
295	437.7	252.1	148.5
296	269.6	132.4	66.0
297	322.4	165.5	87.8
298	359.5	180.3	91.9
299	358.8	226.4	147.3
300	360.9	183.2	94.3
301	210.4	110.5	59.8
302	306.4	157.9	82.8
303	349.3	178.8	93.0
304	126.8	62.0	30.7
305	331.8	178.3	97.2
306	243.1	122.6	62.8
307	470.2	278.4	171.0
308	672.2	353.2	188.9
309	119.1	62.6	33.4
310	444.2	231.0	122.0
311	233.2	115.3	57.9
312	141.5	70.9	36.0
313	450.9	242.2	132.3
314	292.6	153.9	82.6
315	235.4	118.7	60.8
316	283.9	151.4	82.9
317	123.7	63.3	32.8
318	216.7	133.6	84.4
319	453.1	276.6	173.5
320	324.7	176.4	97.5
321	268.0	141.2	76.0
322	403.4	211.0	112.4
323	115.0	60.7	32.6
324	715.6	421.3	256.4
325	259.9	130.6	66.8

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
326	700.2	395.6	227.7
327	170.6	91.2	50.1
328	181.3	87.5	42.9
329	227.1	148.7	101.4
330	102.9	54.8	29.8
331	284.5	162.6	94.4
332	265.3	129.2	63.9
333	957.3	584.0	362.2
334	325.0	173.0	93.5
335	425.6	212.7	107.9
336	241.0	131.2	75.3
337	615.0	331.9	183.1
338	343.6	187.5	104.6
339	548.5	297.8	164.9
340	124.9	59.3	28.5
341	673.0	402.7	247.3
342	199.6	96.9	47.7
343	125.2	67.2	36.8
344	254.2	145.0	84.4
345	190.7	94.0	47.0
346	197.3	98.7	50.3
347	424.4	257.6	161.8
348	499.1	274.0	154.8
349	340.7	190.0	110.2
350	402.9	217.0	119.1
351	415.3	210.4	108.1
352	256.3	137.3	75.6
353	524.1	283.3	155.4
354	352.8	190.5	105.0
355	285.4	152.2	83.7
356	252.8	130.3	68.2
357	62.4	34.3	19.4
358	202.8	101.6	51.8
359	363.5	183.4	93.9
360	428.7	235.8	132.1
361	265.4	130.8	65.4
362	428.5	214.8	109.3

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
363	433.1	220.4	114.3
364	520.0	297.3	174.4
365	417.1	210.2	107.5
366	267.5	130.1	64.2
367	415.6	241.9	143.3
368	580.2	325.3	185.8
369	340.8	186.4	105.6
370	651.9	356.6	199.8
371	165.4	83.4	43.1
372	277.1	143.7	76.1
373	466.5	261.3	150.4
374	404.0	243.6	152.3
375	100.9	56.5	32.4
376	198.1	103.3	55.3
377	127.3	66.3	35.2
378	274.1	146.1	79.0
379	284.1	146.3	76.6
380	184.1	93.5	48.3
381	313.1	167.3	91.0
382	243.3	121.9	62.1
383	346.7	192.5	109.2
384	407.7	228.7	131.2
385	260.0	165.3	107.7
386	396.4	224.1	131.6
387	471.9	240.6	124.6
388	182.4	100.9	56.9
389	712.8	399.1	227.5
390	239.4	132.5	75.5
391	262.8	132.9	68.3
392	342.3	175.6	91.4
393	637.7	383.7	238.4
394	774.0	430.4	243.9
395	52.8	26.8	13.8
396	446.3	237.7	129.9
397	494.3	262.0	142.1
398	369.2	189.1	98.8
399	126.2	71.0	40.7

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
400	127.2	66.1	34.9
401	446.6	226.6	116.8
402	395.1	218.9	123.3
403	46.9	23.3	11.8
404	646.0	345.9	188.2
405	460.6	241.2	129.0
406	262.6	137.9	73.6
407	125.7	60.3	29.4
408	421.7	251.6	154.0
409	397.0	204.0	106.7
410	1256.7	844.4	587.8
411	485.7	274.5	160.9
412	374.9	221.2	138.6
413	135.2	73.5	41.5
414	235.3	120.5	62.6
415	532.1	298.0	172.6
416	188.3	97.4	51.3
417	681.6	416.9	267.4
418	289.5	148.6	77.7
419	67.6	35.0	18.4
420	436.2	218.5	111.1
421	202.4	121.2	75.2
422	318.8	220.9	161.0
423	688.2	414.4	254.8
424	576.5	318.7	180.8
425	104.2	52.2	26.5
426	321.7	195.4	120.3
427	333.4	172.5	90.8
428	196.4	96.6	48.1
429	256.6	136.9	74.8
430	246.9	167.2	114.7
431	141.3	69.3	34.5
432	299.7	156.9	83.3
433	412.3	249.5	154.8
434	217.9	108.8	55.1
435	245.7	126.5	66.0
436	892.9	601.1	411.1

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
437	166.9	94.4	55.0
438	217.6	128.5	80.5
439	219.7	110.9	57.0
440	642.9	358.5	203.1
441	235.3	130.6	75.7
442	370.2	207.6	120.7
443	135.9	67.0	33.5
444	181.1	97.5	53.7
445	244.1	132.7	73.8
446	184.3	100.8	56.3
447	225.8	112.7	57.0
448	470.6	258.6	144.6
449	313.6	159.1	82.3
450	129.5	63.8	32.0
451	336.3	169.8	87.2
452	345.7	194.2	111.0
453	178.2	91.5	48.1
454	171.8	95.3	54.0
455	417.9	215.5	112.8
456	216.4	110.5	57.2
457	69.6	35.2	18.1
458	217.6	132.8	85.6
459	431.1	232.2	128.5
460	475.1	272.0	161.5
461	314.7	175.4	100.1
462	299.0	152.2	79.0
463	152.3	76.8	39.3
464	335.5	183.1	101.8
465	232.2	112.7	55.5
466	153.8	79.1	41.2
467	479.4	247.8	130.1
468	240.8	126.7	68.0
469	450.4	288.5	194.3
470	203.5	104.9	55.2
471	584.0	323.7	185.3
472	46.1	22.4	11.0
473	313.0	154.4	77.3

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
474	272.4	142.3	75.8
475	45.5	21.8	10.6
476	229.4	121.6	66.3
477	224.7	155.0	110.9
478	646.7	369.2	215.1
479	453.0	260.3	155.6
480	59.8	29.5	14.7
481	453.3	240.7	130.1
482	208.2	105.0	53.9
483	244.5	126.0	65.7
484	655.3	451.5	320.2
485	119.2	74.8	49.9
486	357.3	199.1	115.0
487	325.5	164.9	85.5
488	603.6	348.4	204.0
489	532.5	317.7	194.9
490	821.7	489.0	296.0
491	127.5	63.2	31.8
492	161.7	97.0	59.6
493	337.9	173.7	90.7
494	684.8	430.5	274.5
495	138.1	77.4	44.2
496	236.2	122.3	64.5
497	105.7	51.3	25.4
498	128.2	71.1	40.2
499	559.1	340.5	213.9
500	153.8	75.8	37.9
501	308.2	153.9	78.1
502	87.1	42.0	20.5
503	414.8	220.5	119.2
504	196.2	103.7	55.9
505	138.7	78.3	45.1
506	212.5	109.8	57.5
507	185.5	98.0	53.2
508	450.0	228.9	118.9
509	131.3	81.4	52.7
510	138.9	69.0	34.8

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
511	117.7	66.6	39.0
512	240.1	123.3	64.5
513	262.9	135.4	70.9
514	738.5	407.7	230.7
515	115.2	60.3	32.0
516	251.4	128.2	66.8
517	115.2	64.6	37.0
518	263.6	139.6	75.8
519	371.2	212.9	125.1
520	360.8	181.9	93.2
521	297.5	147.3	74.1
522	176.1	86.6	43.4
523	189.5	94.4	47.8
524	241.1	117.5	58.2
525	386.6	199.5	104.5
526	163.8	85.0	45.0
527	233.9	113.4	55.8
528	107.5	58.1	32.0
529	267.2	148.9	86.3
530	417.2	222.4	121.3
531	304.9	150.8	75.7
532	436.0	225.5	118.5
533	86.6	53.5	34.1
534	212.3	103.6	51.4
535	571.3	315.9	180.3
536	487.1	262.9	144.2
537	355.7	178.7	91.2
538	586.5	349.3	212.7
539	596.7	327.1	182.8
540	298.7	158.8	86.0
541	162.2	82.2	42.3
542	108.5	52.3	25.6
543	177.2	89.3	45.6
544	553.2	323.2	194.6
545	432.3	282.9	188.4
546	297.1	155.0	82.8
547	339.1	183.0	100.6

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
548	264.1	143.2	80.1
549	277.1	154.8	88.0
550	245.1	161.1	107.7
551	297.7	171.6	102.9
552	322.9	178.1	101.4
553	144.9	71.9	36.2
554	157.1	81.1	42.9
555	267.2	134.9	69.1
556	182.1	95.3	51.2
557	327.1	196.6	121.2
558	141.5	70.0	35.2
559	253.6	123.7	61.2
560	87.5	44.5	23.1
561	266.8	155.2	94.2
562	398.5	207.6	109.8
563	472.6	248.1	132.1
564	590.5	332.3	189.7
565	298.4	204.0	141.6
566	264.5	138.6	74.2
567	409.5	214.5	114.0
568	513.6	263.9	137.8
569	397.1	214.3	117.7
570	200.0	101.2	52.3
571	313.6	173.4	99.2
572	485.4	262.0	144.0
573	175.8	90.0	46.9
574	192.5	109.5	64.2
575	290.9	143.3	71.6
576	144.9	70.7	35.1
577	334.0	199.9	124.1
578	178.4	87.6	43.7
579	145.7	83.0	48.5
580	181.4	89.3	44.7
581	217.1	106.3	52.8
582	172.3	94.5	52.5
583	308.3	183.7	115.2
584	169.9	85.2	43.3

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
585	176.1	84.6	41.2
586	250.1	121.7	60.1
587	271.7	132.4	65.5
588	333.3	170.1	88.4
589	432.2	268.4	171.2
590	132.1	64.5	32.0
591	911.1	502.0	281.1
592	356.2	205.9	123.4
593	447.9	244.6	136.0
594	120.1	58.8	29.2
595	193.9	101.7	55.0
596	730.0	420.9	251.0
597	335.1	181.5	100.1
598	361.2	194.9	107.3
599	260.4	134.9	71.3
600	324.5	164.4	84.5
601	208.1	109.7	58.8
602	382.3	209.2	116.0
603	441.2	231.8	123.5
604	377.3	188.7	96.0
605	156.0	79.3	41.1
606	117.6	58.1	29.3
607	472.8	262.8	148.3
608	186.9	97.9	52.9
609	187.9	97.7	51.9
610	547.6	342.9	219.0
611	338.6	179.8	98.3
612	261.3	133.6	69.5
613	482.1	248.7	130.2
614	651.5	385.8	233.3
615	480.7	262.8	148.8
616	485.9	249.3	130.0
617	334.8	189.6	109.0
618	221.9	128.2	77.7
619	218.3	108.9	55.3
620	112.0	55.7	28.3
621	400.3	210.6	113.2

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
622	158.4	78.5	39.4
623	181.1	89.1	44.5
624	257.9	137.6	74.6
625	244.9	121.4	61.2
626	492.8	272.2	155.6
627	440.1	235.6	128.7
628	192.5	95.9	48.6
629	175.2	88.4	45.3
630	481.9	258.7	141.7
631	240.4	117.6	58.5
632	242.8	145.4	91.8
633	276.2	145.8	78.8
634	349.7	179.9	94.4
635	82.2	43.9	24.1
636	194.9	95.1	47.2
637	292.5	169.5	101.1
638	114.8	54.7	26.5
639	416.8	227.8	127.2
640	709.8	373.3	199.8
641	321.1	173.9	97.5
642	717.8	427.5	259.4
643	409.6	208.4	107.7
644	398.6	204.6	106.8
645	118.4	58.0	28.8
646	165.8	89.3	50.2
647	341.7	182.9	100.0
648	624.6	328.4	175.4
649	322.9	175.3	97.1
650	269.4	135.9	69.8
651	400.3	212.2	114.3
652	473.9	297.1	194.0
653	630.7	342.4	190.4
654	614.9	337.0	187.7
655	265.2	173.4	120.0
656	319.7	160.6	82.0
657	351.4	192.2	109.3
658	615.1	348.8	201.0

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
659	254.6	142.2	85.0
660	150.0	77.8	41.2
661	28.7	13.8	6.7
662	1207.3	727.1	446.2
663	396.1	212.5	116.4
664	465.1	237.3	123.0
665	106.1	55.0	29.0
666	234.9	135.4	82.5
667	262.6	130.5	65.8
668	330.1	198.1	125.5
669	584.1	313.5	172.8
670	428.4	243.4	141.9
671	193.3	93.8	46.2
672	470.6	257.7	144.5
673	478.8	247.8	130.4
674	118.6	58.8	29.7
675	654.4	410.8	263.4
676	354.5	194.6	108.9
677	533.0	296.4	170.7
678	201.3	98.6	49.0
679	313.6	173.2	97.4
680	340.3	216.8	144.5
681	176.9	88.8	45.3
682	421.9	219.7	116.8
683	210.4	107.5	56.3
684	209.3	101.4	49.8
685	401.2	208.3	110.1
686	364.2	201.7	114.8
687	143.6	73.8	38.5
688	448.0	239.5	130.9
689	302.8	161.7	87.8
690	570.5	301.9	162.3
691	864.2	481.7	273.1
692	932.2	603.4	400.1
693	105.3	54.5	28.9
694	311.6	159.1	82.8
695	326.5	168.1	87.8

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
696	217.8	104.9	51.3
697	666.9	397.0	239.4
698	640.3	397.1	259.3
699	158.1	76.3	37.4
700	169.2	80.8	39.2
701	211.7	114.4	63.4
702	164.5	88.8	48.9
703	83.5	41.5	21.0
704	148.1	78.5	42.3
705	172.3	93.6	51.6
706	373.0	194.5	103.1
707	321.3	160.0	80.9
708	645.7	340.4	182.7
709	330.6	178.9	98.3
710	254.5	139.9	78.4
711	866.1	483.2	276.8
712	445.7	236.3	127.1
713	149.7	79.0	42.3
714	113.6	56.5	28.7
715	227.2	117.1	61.4
716	204.5	111.9	63.7
717	400.4	230.1	134.9
718	379.8	198.5	105.6
719	201.3	107.3	58.1
720	467.0	261.1	151.7
721	557.2	303.8	169.1
722	282.0	138.4	68.9
723	192.3	96.1	48.9
724	684.5	441.0	289.2
725	528.9	284.4	155.3
726	919.7	542.3	325.8
727	579.6	306.5	165.5
728	524.2	293.2	168.2
729	120.7	57.2	27.5
730	651.8	379.9	226.2
731	158.7	85.7	47.1
732	457.8	253.5	142.8

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
733	100.5	47.3	22.6
734	2.1	1.0	0.5
735	240.8	124.6	65.7
736	448.2	237.8	128.6
737	301.5	157.0	83.0
738	384.2	246.0	166.7
739	1080.8	656.1	410.7
740	106.1	52.6	26.5
741	268.6	140.6	76.4
742	188.0	97.9	51.8
743	268.2	138.2	72.4
744	523.8	269.6	141.1
745	105.1	55.9	30.4
746	557.4	291.2	154.7
747	671.5	379.5	217.7
748	433.7	221.2	114.5
749	504.3	280.0	159.4
750	173.3	88.4	46.0
751	439.8	228.7	120.9
752	508.4	302.0	186.2
753	260.7	146.8	83.7
754	493.6	320.0	219.1
755	430.3	247.2	144.1
756	268.9	149.9	87.2
757	302.1	162.8	89.2
758	245.9	130.2	70.4
759	488.9	265.6	146.9
760	494.4	289.2	175.3
761	104.6	52.1	26.3
762	466.6	263.1	150.6
763	97.1	47.9	24.0
764	363.3	187.2	98.1
765	177.7	90.6	47.0
766	129.0	64.6	32.9
767	196.0	109.8	63.0
768	706.2	416.5	250.6
769	220.2	123.3	69.8

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
770	607.4	321.9	173.7
771	506.1	298.5	185.2
772	96.7	47.8	24.0
773	115.8	62.0	33.7
774	294.6	175.1	108.8
775	389.2	215.3	122.0
776	133.1	71.6	39.6
777	113.2	62.2	34.9
778	139.5	73.0	39.0
779	152.0	80.9	44.1
780	165.2	92.4	52.5
781	569.5	305.0	166.6
782	196.2	114.5	70.6
783	129.1	66.7	34.9
784	170.2	88.1	46.8
785	187.4	91.0	45.1
786	212.5	116.2	64.9
787	233.1	114.5	57.3
788	244.2	127.8	68.2
789	497.6	264.5	142.8
790	416.1	210.1	107.9
791	291.6	152.0	82.1
792	372.8	193.2	101.6
793	385.0	204.3	110.0
794	426.4	215.0	110.0
795	474.6	252.8	137.4
796	364.6	196.3	107.6
797	292.2	224.2	175.1
798	311.4	165.1	91.1
799	80.6	48.1	29.4
800	378.8	192.6	99.6
801	218.5	113.2	59.9
802	179.9	110.3	70.7
803	610.4	343.9	199.1
804	302.4	151.1	76.7
805	450.2	240.8	131.0
806	555.8	305.5	171.2

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
807	138.4	70.5	36.5
808	751.6	408.5	228.2
809	82.2	40.2	19.9
810	197.0	99.8	51.4
811	394.2	211.7	116.5
812	447.6	231.7	121.9
813	300.7	148.3	74.3
814	455.6	234.0	121.9
815	342.2	207.3	127.6
816	938.3	603.2	401.9
817	192.4	94.8	47.8
818	347.9	201.4	120.2
819	184.4	91.3	45.9
820	454.4	246.4	135.7
821	322.8	169.8	91.1
822	140.2	73.1	38.7
823	456.6	238.3	126.6
824	174.8	86.9	43.7
825	175.0	87.5	44.4
826	189.6	95.1	48.7
827	268.8	130.7	64.5
828	483.3	254.8	136.6
829	204.3	114.5	65.5
830	392.6	239.9	149.7
831	474.5	253.8	138.2
832	241.8	130.2	72.6
833	330.6	175.0	93.9
834	355.6	193.5	109.1
835	282.0	147.3	78.2
836	185.5	90.7	45.0
837	259.0	137.0	73.5
838	151.7	75.1	37.8
839	183.3	97.2	52.6
840	247.6	140.7	84.2
841	199.7	102.4	53.4
842	476.0	274.9	165.4
843	593.8	312.0	166.5

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
844	421.2	229.3	127.4
845	463.9	234.0	119.8
846	170.5	86.6	44.8
847	777.5	483.0	309.8
848	206.8	102.5	51.7
849	729.0	467.7	306.4
850	409.9	220.2	121.9
851	191.4	105.3	59.1
852	338.8	175.0	92.0
853	346.1	189.2	104.8
854	245.3	133.8	74.1
855	659.7	359.1	199.1
856	123.0	59.7	29.5
857	154.3	75.1	37.1
858	165.0	81.7	41.0
859	326.6	164.3	84.0
860	261.3	162.1	102.1
861	260.0	127.7	63.7
862	335.0	171.9	89.7
863	639.8	343.6	188.9
864	353.7	177.2	90.0
865	339.8	168.8	85.1
866	154.1	85.5	48.4
867	293.8	147.5	75.1
868	101.4	56.2	31.6
869	268.9	151.4	87.5
870	211.0	108.0	56.3
871	321.6	161.8	82.8
872	135.0	80.8	50.4
873	309.6	168.4	93.1
874	366.4	202.1	113.7
875	74.0	36.6	18.4
876	513.7	328.0	215.0
877	189.4	111.3	67.5
878	401.4	255.0	164.8
879	823.4	476.8	284.4
880	574.4	322.6	186.6

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
881	258.6	126.0	62.3
882	181.2	96.6	52.4
883	335.0	177.3	96.8
884	102.2	52.5	27.3
885	34.9	16.9	8.3
886	225.0	114.8	59.5
887	768.4	410.4	222.8
888	370.0	201.3	111.1
889	79.6	39.5	19.8
890	331.6	190.4	111.9
891	330.6	173.3	92.3
892	346.9	171.2	85.7
893	556.7	309.4	174.8
894	505.4	301.2	181.9
895	617.2	370.8	232.3
896	260.7	136.7	72.8
897	104.8	49.9	24.1
898	215.1	119.6	67.7
899	247.9	137.7	78.0
900	453.6	252.5	147.3
901	758.4	519.7	368.6
902	586.5	322.0	179.6
903	302.4	157.7	83.8
904	404.9	232.3	138.7
905	463.9	268.1	156.9
906	318.0	159.1	81.0
907	167.8	81.5	40.2
908	1003.8	632.0	404.6
909	390.9	235.8	148.8
910	457.1	242.2	131.2
911	119.5	59.3	30.0
912	284.6	147.8	79.4
913	593.8	355.7	217.3
914	177.8	89.4	45.8
915	137.8	70.3	36.7
916	408.3	225.6	126.3
917	508.2	330.8	220.5

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
918	418.0	236.2	137.3
919	620.7	346.0	196.2
920	185.9	91.9	46.1
921	604.5	320.7	172.6
922	189.3	94.6	48.0
923	253.2	137.5	75.9
924	240.1	118.1	58.9
925	30.9	15.2	7.6
926	997.6	614.0	389.4
927	338.8	183.1	101.6
928	134.1	64.9	31.8
929	505.1	315.1	202.2
930	589.8	348.1	213.5
931	489.4	251.7	131.7
932	881.9	496.9	286.3
933	358.0	183.3	95.3
934	450.9	244.9	135.8
935	486.6	283.4	168.1
936	206.1	109.6	59.0
937	205.3	101.3	50.8
938	174.6	89.4	46.7
939	203.0	104.1	55.3
940	429.9	228.9	123.9
941	180.6	109.2	68.2
942	800.4	460.9	270.1
943	138.5	69.9	35.9
944	453.2	235.7	124.7
945	1060.0	618.3	367.2
946	178.4	100.4	58.1
947	631.1	338.4	184.7
948	355.4	218.9	142.0
949	135.8	65.5	32.2
950	257.7	142.9	81.6
951	168.4	87.2	45.9
952	316.9	155.9	77.8
953	144.3	72.3	36.7
954	323.0	168.4	89.4

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
955	248.2	121.9	60.7
956	213.9	119.2	69.8
957	370.4	205.9	116.9
958	227.9	116.8	60.8
959	306.3	185.8	115.9
960	179.9	93.4	49.3
961	293.9	203.3	145.9
962	357.5	196.2	109.6
963	189.6	92.0	45.3
964	386.3	208.3	115.0
965	135.3	66.5	33.5
966	108.3	56.0	29.5
967	491.1	290.9	176.6
968	256.8	132.5	70.1
969	833.9	512.4	321.5
970	812.0	549.2	381.1
971	339.6	174.0	91.3
972	204.3	100.3	50.0
973	213.4	106.8	54.6
974	403.3	266.1	180.3
975	549.2	285.1	150.5

Sequence	PV (million cub meter) for discount rate		
	6%	8%	10%
976	89.4	43.3	21.3
977	184.3	103.9	61.3
978	311.0	172.2	99.3
979	250.8	134.1	73.2
980	483.9	272.4	157.4
981	108.1	58.9	32.6
982	69.3	32.4	15.4
983	707.2	448.9	294.7
984	343.7	184.2	101.1
985	384.2	209.3	117.2
986	487.5	278.1	163.7
987	197.9	98.4	49.6
988	398.4	213.9	116.9
989	206.1	111.3	61.5
990	576.3	314.5	175.2
991	132.2	69.0	36.6
992	340.3	175.2	92.0
993	438.9	242.0	136.1
994	946.5	549.6	325.9
995	263.7	136.4	72.0
Mean	335.3	184.8	104.9

ANNEXURE 6-B

Results of *Comparative Study* shadow priced

Incremental Approach corrected for shadow pricing of electricity

INPUT

Tugela Vaal Water Project - D3, L4, High

Maximum Vaal Augmentation **396 mill m^3/a**

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**Oct-07**	**Oct-07**	**Pre engineering**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
		R'000	**R'000**						
Jana Dam	FSL 890	5 728 300	322 400	4.50%	10%	0.25%	1%	50	30
Mielietuin		0	0	4.50%	10%	0.25%	1%	50	30
Pipelines - Jana to Kilburn	Q = 12,55	3 425 900	0	4.50%	10%	0.25%	3%	50	30
Pump stations - Jana to Kilburn	Q = 12,55	88 400	395 800	4.50%	10%	0.25%	3%	50	30
Roads - excl Mielietuin		182 144	0	4.50%	10%	0.25%	3%	50	30
Electricity supply		0	0	4.50%	10%	0.50%	3%	50	30
Camps		0	0	4.50%	10%	0.25%	3%	50	30
Raise Vioolsdrif Dam	Add Yield 0	0	0	4.50%	10%	0.25%	1%	50	30

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost	8%	811 435	
Environmental cost		55 328	
Social cost		75 348	
Electricity			1 135 166
Royalty			0

Results	**Total**	**6%**	**8%**	**10%**
	R'000	**R/m^3**	**R/m^3**	**R/m^3**
PV Costs	51 882 997	14 609 309	10 835 593	8 375 306
PV Water	13 748 075	2 330 141	1 424 136	906 365
URV	3.77	6.27	7.61	9.24

ANNEXURE 6-B (cont'd)

Incremental Approach corrected for shadow pricing of electricity

ELECTRICITY:

Tugela Vaal Water Project - D3, L4, High

Maximum Vaal Augmentation **396.0 mill m3/a**

Pump stations	Q costed	KW	Q model	KW	MWH/annum
Jana	10	43200	12.55	54216	
Rustenburg	15	32700	12.55	27359	
Bethany	15	14750	12.55	12341	
Total		**90650**		**93916**	**822 703**
Power factor				0.85	
KVA				**110 489**	

	Approx H	Q model	Efficiency	KW equival(	MWH/annum
Drakensberg	440	12.55	0.85	63 730	**558 278**

Shadow price for energy (Rand/kWh)			**0.822**
Total max annual energy	MWh/annum		**1 380 981**
Average energy per unit transfer	kWh/cub m		**3.49**
Energy charge per unit transferred	R/cub m		**2.87**
Total max annual energy charge	R'000		**1 135 166**

ANNEXURE 6-B (cont'd)

CASHFLOW
Tugela Vaal Water Project - D3, L4, High
Maximum
Vaal **396.0 mill m3/a**

	Jana Dam					Mielietuin					Pipelines - Jana to Kilburn					Pump stations - Jana to Kilburn				
	Civil	M&E	Pre engine	Supervisio	Maintenan	Civil	M&E	Pre engine	Supervisio	Maintenan	Civil	M&E	Pre engine	Supervisio	Maintenan	Civil	M&E	Pre engine	Supervisio	Maintenan
2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	54 456	0	0	0	0	0	0	0	0	0	30 833	0	0	0	0	4 358	0	0
2011	0	0	81 684	0	0	0	0	0	0	0	0	0	46 250	0	0	0	0	6 537	0	0
2012	0	0	81 684	0	0	0	0	0	0	0	0	0	46 250	0	0	0	0	6 537	0	0
2013	0	0	54 456	0	0	0	0	0	0	0	0	0	30 833	0	0	0	0	4 358	0	0
2014	1 145 660	64 480	0	121 014	0	0	0	0	0	0	685 180	0	0	68 518	0	17 680	79 160	0	9 684	0
2015	1 145 660	64 480	0	121 014	0	0	0	0	0	0	685 180	0	0	68 518	0	17 680	79 160	0	9 684	0
2016	1 145 660	64 480	0	121 014	0	0	0	0	0	0	685 180	0	0	68 518	0	17 680	79 160	0	9 684	0
2017	1 145 660	64 480	0	121 014	0	0	0	0	0	0	685 180	0	0	68 518	0	17 680	79 160	0	9 684	0
2018	1 145 660	64 480	0	121 014	0	0	0	0	0	0	685 180	0	0	68 518	0	17 680	79 160	0	9 684	0
2019	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2020	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2021	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2022	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2023	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2024	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2025	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2026	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2027	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2028	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2029	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2030	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2031	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2032	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2033	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2034	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2035	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2036	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2037	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2038	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2039	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2040	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2041	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2042	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2043	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2044	0	64 480	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	79 160	0	0	12 095
2045	0	64 480	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	79 160	0	0	12 095
2046	0	64 480	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	79 160	0	0	12 095
2047	0	64 480	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	79 160	0	0	12 095
2048	0	64 480	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	79 160	0	0	12 095
2049	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2050	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2051	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2052	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2053	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2054	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2055	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2056	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2057	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
2058	0	0	0	0	17 545	0	0	0	0	0	0	0	0	0	8 565	0	0	0	0	12 095
Sub-total	**5 728 300**	**644 800**	**272 282**	**605 070**	**701 790**	**0**	**0**	**0**	**0**	**0**	**3 425 900**	**0**	**154 166**	**342 590**	**342 590**	**88 400**	**791 600**	**21 789**	**48 420**	**483 800**
Residual value	-1 145 660	-214 933				0	0				-685 180	0				-17 680	-263 867			

ANNEXURE 6-B (cont'd)

	Roads - excl Mielietuin				Admin cost	Environmental cost		Social cost		Electricity	Total	Discount		
	Civil	Pre engineering	Supervision	Maintenance	Capital	Capital	Annual	Capital	Annual	Annual		6%	8%	10%
2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	2 459	0	0	162 287	27 664	0	37 674	0	0	319 731	268 453	253 813	240 219
2011	0	3 279	0	0	81 144	27 664	0	37 674	0	0	284 231	225 138	208 918	194 134
2012	72 857	2 459	7 286	0	81 144	0	0	0	0	0	298 216	222 845	202 961	185 169
2013	72 857	0	7 286	0	81 144	0	0	0	0	0	250 934	176 898	158 131	141 646
2014	36 429	0	3 643	0	81 144	0	0	0	0	0	2 312 591	1 538 005	1 349 375	1 186 725
2015	0	0	0	455	81 144	0	0	0	0	0	2 272 975	1 426 093	1 228 018	1 060 360
2016	0	0	0	455	81 144	0	0	0	0	0	2 272 975	1 345 370	1 137 053	963 963
2017	0	0	0	455	81 144	0	0	0	0	0	2 272 975	1 269 217	1 052 827	876 330
2018	0	0	0	455	81 144	0	0	0	0	0	2 272 975	1 197 375	974 840	796 664
2019	0	0	0	455	0	0	0	0	0	389 375	428 035	212 720	169 979	136 385
2020	0	0	0	455	0	0	0	0	0	459 904	498 564	233 746	183 321	144 416
2021	0	0	0	455	0	0	0	0	0	498 800	537 460	237 719	182 984	141 530
2022	0	0	0	455	0	0	0	0	0	539 783	578 442	241 364	182 349	138 475
2023	0	0	0	455	0	0	0	0	0	581 102	619 762	243 967	180 903	134 878
2024	0	0	0	455	0	0	0	0	0	626 973	665 633	247 192	179 900	131 692
2025	0	0	0	455	0	0	0	0	0	666 356	705 016	246 998	176 430	126 803
2026	0	0	0	455	0	0	0	0	0	717 605	756 265	249 955	175 236	123 655
2027	0	0	0	455	0	0	0	0	0	769 682	808 341	252 045	173 428	120 155
2028	0	0	0	455	0	0	0	0	0	822 597	861 257	253 343	171 094	116 382
2029	0	0	0	455	0	0	0	0	0	877 030	915 689	254 108	168 432	112 489
2030	0	0	0	455	0	0	0	0	0	936 550	975 210	255 307	166 093	108 910
2031	0	0	0	455	0	0	0	0	0	992 227	1 030 887	254 607	162 570	104 661
2032	0	0	0	455	0	0	0	0	0	1 048 242	1 086 901	253 247	158 707	100 317
2033	0	0	0	455	0	0	0	0	0	1 104 596	1 143 255	251 299	154 570	95 925
2034	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	243 414	146 948	89 537
2035	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	229 636	136 063	81 397
2036	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	216 638	125 984	73 997
2037	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	204 375	116 652	67 270
2038	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	192 807	108 011	61 155
2039	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	181 893	100 010	55 595
2040	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	171 597	92 602	50 541
2041	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	161 884	85 742	45 947
2042	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	152 721	79 391	41 770
2043	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	144 076	73 510	37 972
2044	0	0	0	455	0	0	0	0	0	1 135 166	1 317 466	152 554	76 394	38 745
2045	0	0	0	455	0	0	0	0	0	1 135 166	1 317 466	143 918	70 735	35 222
2046	0	0	0	455	0	0	0	0	0	1 135 166	1 317 466	135 772	65 496	32 020
2047	0	0	0	455	0	0	0	0	0	1 135 166	1 317 466	128 087	60 644	29 109
2048	0	0	0	455	0	0	0	0	0	1 135 166	1 317 466	120 837	56 152	26 463
2049	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	101 568	46 324	21 434
2050	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	95 819	42 893	19 486
2051	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	90 395	39 715	17 714
2052	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	85 279	36 773	16 104
2053	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	80 451	34 050	14 640
2054	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	75 898	31 527	13 309
2055	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	71 602	29 192	12 099
2056	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	67 549	27 030	10 999
2057	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	63 725	25 027	9 999
2058	0	0	0	455	0	0	0	0	0	1 135 166	1 173 826	60 118	23 174	9 090
Sub-total	**182 144**	**8 196**	**18 214**	**20 036**	**811 435**	**55 328**	**0**	**75 348**	**0**	**39 409 976**	**54 232 174**	**14 729 623**	**10 881 970**	**8 393 498**
Residual value	-21 857				0	0	0	0	0	0	-2 349 177	-120 314	-46 377	-18 192
											51 882 997	**14 609 309**	**10 835 593**	**8 375 306**

ANNEXURE 6-B (cont'd)

WATER AUGMENTATION

Tugela Vaal Water Project - D3, L4, High

Maximum Vaal Augment 396.0 mill m3/a

	Average Demand	Yield	Net Demand	Vaal Augmentation	Additonal pumping TWP	Total TWP pumping	Total"effectiveness" measure	Effectiveness discounted		
	mill m^3/a	mill m^3/a	mill m^3/a	mill m^3/a	mill m^3/a	mill m^3/a	mill m^3/a	6%	8%	10%
2007	2952	2877			0	0.0	0.0	0.00	0.00	0.00
2008	2996	2877	119.4		0	0.0	0.0	0.00	0.00	0.00
2009	2946	2877	68.6		0	0.0	0.0	0.00	0.00	0.00
2010	2889	2877	11.6		0	0.0	0.0	0.00	0.00	0.00
2011	2827	2877	-49.6		0	0.0	0.0	0.00	0.00	0.00
2012	2831	2877	-46.5		0	0.0	0.0	0.00	0.00	0.00
2013	2859	2877	-18.0		0	0.0	0.0	0.00	0.00	0.00
2014	2889	2877	12.4		0	0.0	0.0	0.00	0.00	0.00
2015	2920	2877	42.5		0	0.0	0.0	0.00	0.00	0.00
2016	2940	2877	63.3		0	0.0	0.0	0.00	0.00	0.00
2017	2964	2877	86.9		0	0.0	0.0	0.00	0.00	0.00
2018	2988	2877	111.0		0	0.0	0.0	0.00	0.00	0.00
2019	3013	2877	135.8	135.8	0	135.8	135.8	67.50	53.94	43.28
2020	3037	2877	160.4	160.4	0	160.4	160.4	75.22	58.99	46.47
2021	3051	2877	174.0	174.0	0	174.0	174.0	76.96	59.24	45.82
2022	3065	2877	188.3	188.3	0	188.3	188.3	78.57	59.36	45.08
2023	3080	2877	202.7	202.7	0	202.7	202.7	79.80	59.17	44.12
2024	3096	2877	218.7	218.7	0	218.7	218.7	81.22	59.11	43.27
2025	3109	2877	232.5	232.5	0	232.5	232.5	81.44	58.17	41.81
2026	3127	2877	250.3	250.3	0	250.3	250.3	82.74	58.01	40.93
2027	3146	2877	268.5	268.5	0	268.5	268.5	83.72	57.61	39.91
2028	3164	2877	287.0	287.0	0	287.0	287.0	84.41	57.01	38.78
2029	3183	2877	305.9	305.9	0	305.9	305.9	84.90	56.28	37.58
2030	3204	2877	326.7	326.7	0	326.7	326.7	85.53	55.64	36.49
2031	3223	2877	346.1	346.1	0	346.1	346.1	85.49	54.59	35.14
2032	3243	2877	365.7	365.7	0	365.7	365.7	85.20	53.40	33.75
2033	3262	2877	385.3	385.3	0	385.3	385.3	84.70	52.10	32.33
2034	3282	2877	405.1	396.0	0	396.0	396.0	82.12	49.57	30.21
2035	3302	2877	425.0	396.0	0	396.0	396.0	77.47	45.90	27.46
2036	3322	2877	445.0	396.0	0	396.0	396.0	73.08	42.50	24.96
2037	3342	2877	465.2	396.0	0	396.0	396.0	68.95	39.35	22.69
2038	3362	2877	485.4	396.0	0	396.0	396.0	65.04	36.44	20.63
2039	3383	2877	505.8	396.0	0	396.0	396.0	61.36	33.74	18.76
2040	3403	2877	526.3	396.0	0	396.0	396.0	57.89	31.24	17.05
2041				396.0		396.0	396.0	54.61	28.93	15.50
2042				396.0		396.0	396.0	51.52	26.78	14.09
2043				396.0		396.0	396.0	48.61	24.80	12.81
2044				396.0		396.0	396.0	45.85	22.96	11.65
2045				396.0		396.0	396.0	43.26	21.26	10.59
2046				396.0		396.0	396.0	40.81	19.69	9.62
2047				396.0		396.0	396.0	38.50	18.23	8.75
2048				396.0		396.0	396.0	36.32	16.88	7.95
2049				396.0		396.0	396.0	34.26	15.63	7.23
2050				396.0		396.0	396.0	32.33	14.47	6.57
2051				396.0		396.0	396.0	30.50	13.40	5.98
2052				396.0		396.0	396.0	28.77	12.41	5.43
2053				396.0		396.0	396.0	27.14	11.49	4.94
2054				396.0		396.0	396.0	25.60	10.64	4.49
2055				396.0		396.0	396.0	24.16	9.85	4.08
2056				396.0		396.0	396.0	22.79	9.12	3.71
2057				396.0		396.0	396.0	21.50	8.44	3.37
2058				396.0		396.0	396.0	20.28	7.82	3.07
			PV	**13 748**				**2 330**	**1 424**	**906**

ANNEXURE 6-C

Applying Comprehensive Approach to the TWP: Using expected values for water transfers and electricity costs shadow priced

INPUT — **Transfers stochastic and electricity shadow priced**

Tugela Vaal Water Project - D3, L4, High

Maximum Vaal Augmentation **396 mill m^3/a**

		Civil	M&E	Engineering		Maintenance		Useful life	
Element		**Oct-07**	**Oct-07**	**Pre engineer**	**Supervision**	**Civil**	**M&E**	**Civil**	**M&E**
		R'000	**R'000**						
Jana Dam	FSL 890	5 728 300	322 400	4.50%	10%	0.25%	1%	50	30
Mielietuin		0	0	4.50%	10%	0.25%	1%	50	30
Pipelines - Jana to Kilburn	Q = 12,55	3 425 900	0	4.50%	10%	0.25%	3%	50	30
Pump stations - Jana to Kilburn	Q = 12,55	88 400	395 800	4.50%	10%	0.25%	3%	50	30
Roads - excl Mielietuin		182 144	0	4.50%	10%	0.25%	3%	50	30
Electricity supply		0	0	4.50%	10%	0.50%	3%	50	30
Camps		0	0	4.50%	10%	0.25%	3%	50	30
Raise Vioolsdrif Dam	Add Yield 0	0	0	4.50%	10%	0.25%	1%	50	30

Element		**Capital**	**Annual**
		R'000	**R'000**
Admin cost	8%	811 435	
Environmental cost		55 328	
Social cost		75 348	
Electricity			variable
Royalty			0

Results	**Discount rate**	**6%**	**8%**	**10%**
Expected present value (Oct 2007) of water transfers	million m3	298	158	87
PV of fixed costs	R'000	7 929 771	6 753 191	5 777 137
PV of variable cost	R'000	855 388	454 066	248 533
PV of life-cycle costs	R'000	8 785 159	7 207 258	6 025 670
PV effectiveness of water supply	million m3	2 330	1 424	906
URV	R/m3	3.77	5.06	6.65

ANNEXURE 6-C (cont'd)

ELECTRICITY **Transfers stochastic and electricity shadow priced**

Tugela Vaal Water Project - D3, L4, High
Maximum Vaal Augmentation **396.0 mill m3/a**

Pump stations	Q costed	KW	Q model	KW	MWH/annum
Jana	10	43200	12.55	54216	
Rustenburg	15	32700	12.55	27359	
Bethany	15	14750	12.55	12341	
Total		**90650**		**93916**	**822 703**
Power factor				0.85	
KVA				**110 489**	

	Approx H	Q model	Efficiency	KW equival(	MWH/annum
Drakensberg	440	12.55	0.85	63 730	**558 278**

Average energy requirement for transfer (kWh/m3)			**3.49**
Shadow price for energy (Rand/kWh)			**0.902**
Shadow energy charge per cub meter transferred (Rand)			**3.146**

ANNEXURE 6-D

TWP Transfers: Sequence 410 of 995 – the highest PV transfer volume of all sequences

Year	Annual transfer in million m^3	PV of transfers in million m^3		
		6% discount rate	8% discount rate	10% discount rate
1.0000	0.0000	0.0000	0.0000	0.0000
2.0000	0.0000	0.0000	0.0000	0.0000
3.0000	0.0000	0.0000	0.0000	0.0000
4.0000	0.0000	0.0000	0.0000	0.0000
5.0000	0.0000	0.0000	0.0000	0.0000
6.0000	0.0000	0.0000	0.0000	0.0000
7.0000	0.0000	0.0000	0.0000	0.0000
8.0000	0.0000	0.0000	0.0000	0.0000
9.0000	0.0000	0.0000	0.0000	0.0000
10.0000	0.0000	0.0000	0.0000	0.0000
11.0000	168.3653	88.6927	72.2090	59.0110
12.0000	326.1469	162.0850	129.5174	103.9205
13.0000	464.9909	218.0059	170.9762	134.6913
14.0000	149.9041	66.3027	51.0365	39.4744
15.0000	0.0000	0.0000	0.0000	0.0000
16.0000	107.1468	42.1779	31.2751	23.3183
17.0000	0.0000	0.0000	0.0000	0.0000
18.0000	0.0000	0.0000	0.0000	0.0000
19.0000	0.0000	0.0000	0.0000	0.0000
20.0000	0.0000	0.0000	0.0000	0.0000
21.0000	0.0000	0.0000	0.0000	0.0000
22.0000	0.0000	0.0000	0.0000	0.0000
23.0000	0.0000	0.0000	0.0000	0.0000
24.0000	172.8402	42.6878	27.2568	17.5477
25.0000	464.9909	108.3422	67.8970	42.9168
26.0000	420.8481	92.5066	56.8994	35.3115
27.0000	336.7062	69.8221	42.1512	25.6832
28.0000	312.7855	61.1903	36.2561	21.6896
29.0000	0.0000	0.0000	0.0000	0.0000
30.0000	0.0000	0.0000	0.0000	0.0000
31.0000	173.3640	28.4759	15.9523	9.0320
32.0000	464.9909	72.0538	39.6172	22.0231
33.0000	321.6784	47.0250	25.3769	13.8504
34.0000	464.9909	64.1276	33.9654	18.2009
35.0000	0.0000	0.0000	0.0000	0.0000
36.0000	53.1043	6.5181	3.3256	1.7179
37.0000	0.0000	0.0000	0.0000	0.0000
38.0000	24.3396	2.6588	1.3068	0.6507
39.0000	0.0000	0.0000	0.0000	0.0000
40.0000	425.7965	41.3969	19.5998	9.4079
41.0000	464.9909	42.6485	19.8185	9.3399